City of Richmond, Virginia
Department of Public Utilities
Phase III CSO Control Program

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CSO Disinfection Study

FINAL REPORT

June 2005

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City Of Richmond, Virginia
Department Of Public Utilities

CSO Disinfection Study

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CSO Disinfection Study

SECTION 1
SUMMARY

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1.1 BACKGROUND

After the completion of the Phase II Combined Sewer Overflow (CSO) control improvements, the City of Richmond, Virginia conducted a re-evaluation study on its original 1988 CSO Long Term Control Plan (LTCP). The purpose of the study was to reassess the last phase (Phase III) of the original LTCP in light of EPA's 1994 National CSO Control Policy and state-of-the-art technologies. The study identified that after the completion of the Phase II CSO controls approximately 79% of the entire CSO volume will be discharged through the City's largest CSO outfall, Shockoe Creek, at a peak flow rate of 5,000 MGD. The study acknowledged that reliable disinfection of such a large flow rate and volume would be challenging and that inactivation efficiencies greater than 80% may be difficult to achieve and would require further investigations. The receiving water quality model showed that an 80% reduction of bacteriological loading would result in a significant improvement in water quality of the James River.

Under the recommendation of the re-evaluation report, the City conducted a comprehensive disinfection pilot study that evaluated the feasibility of two technologies – ultraviolet (UV) irradiation and chlorination/dechlorination – to achieve a minimum of 80% or possibly higher disinfection efficiency at the Shockoe outfall.

1.2 PURPOSE

The purpose of this report is to evaluate the feasibility and practicality of UV and chlorine to achieve 80% or higher disinfection efficiency at the Shockoe Outfall. This report presents the results of the disinfection pilot study. The conceptual level design criteria and cost effectiveness analysis for the potential UV and chlorination/dechlorination facilities at Shockoe outfall is also provided.

1.3 CONCLUSIONS

The pilot studies described in this report document that reliable disinfection levels of 80% (bacteriological reduction at Shockoe) and higher can be achieved using UV or Sodium Hypochlorite (NaOCl) disinfection. Preliminary cost estimates suggest that the use of NaOCl is more economical. However, the complete life cycle cost analyses must also include tangible costs, intangible factors, O&M considerations and input from the City's staff. Alternatives for cost reductions with UV and with NaOCl include the potential disinfection of lower flow rates at higher levels of bacteriological reductions. These evaluations are included in the development of the Program Project Plan.

1.4 NEXT STEPS – DEVELOPMENT OF THE PROGRAM PROJECT PLAN

Comparative evaluation of the alternative disinfection methods established as technical feasible in this study, in conjunction with expanding the Shockoe Retention Basin.

- Full benefit-cost evaluation based on benefits in terms of illness risk and annual costs, which reflect both capital and O&M requirements.
- Bacteriological model results could be used in the Water Quality Standards Coordination Process
- Finalize the conceptual of the disinfection facilities

SECTION 2
INTRODUCTION

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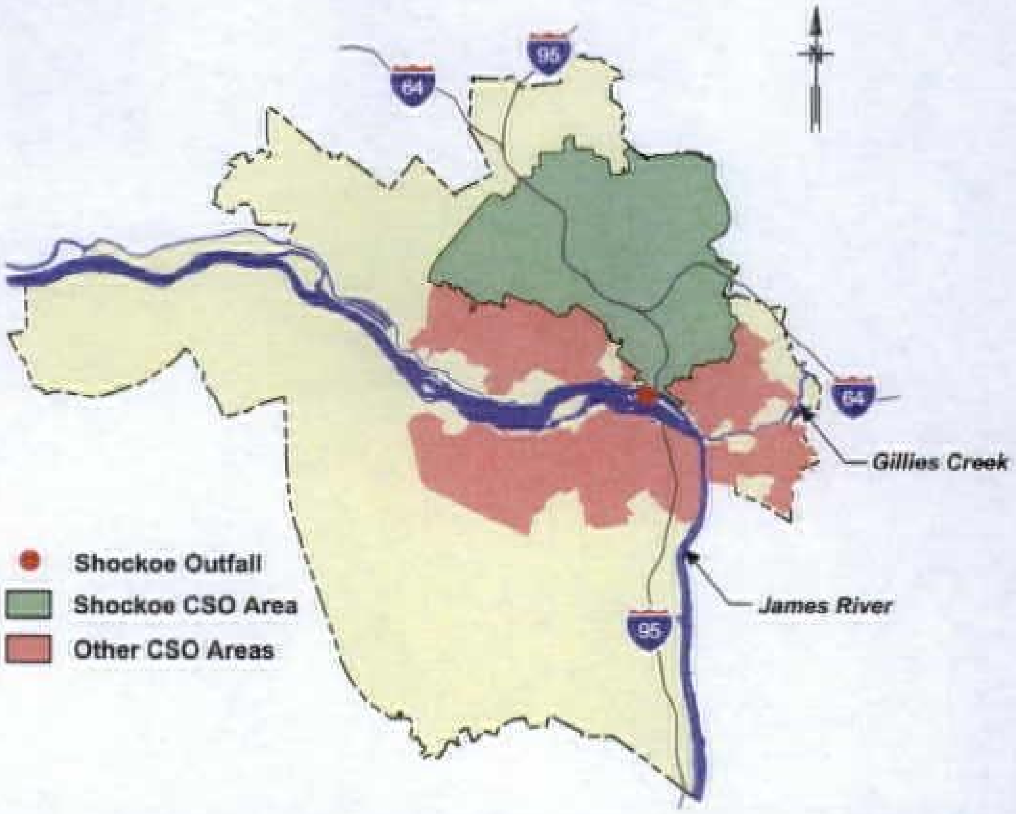
2.1 BACKGROUND

The City of Richmond is located at the falls of the James River. The older portion of the City is served by a combined sewer system (CSS) that comprises about 12,000 acres or 30% of the City's total area. There are currently 29 CSO outfalls identified in City's VPDES permit, most of which are located along the James River and its tributary, Gillies Creek. The largest basin in the system is the Shockoe Creek combined sewer area, which is approximately 7,500 acres or about 65% of the overall system, as shown on **Figure 2-1**.

Figure 2-1
CSO Areas at Richmond, Virginia



The City started its CSO control programs in 1970s. In 1983 the City constructed the Shockoe Retention Basin to retain CSO discharges from the Shockoe Creek CSO area. The Shockoe

Retention Basin is a 50-million-gallon (MG) offline storage facility (35 MG in the retention basin itself and 15 MG in system conduit storage) that retains the "first flush" combined sewer flow for treatment at the wastewater treatment plant (WWTP). In 1987 the City initiated the construction of improvements at WWTP that increased plant capacity during wet weather events to allow the retention basin to be emptied in two days. In 1988 the City completed a comprehensive CSO study defining the Long-Term Control Plan (LTCP) for the CSOs that discharge into James River and Gillies Creek.

The City's CSO LTCP developed a three-phased approach to control the discharge of CSOs. The Phase I improvements consists of the Shockoe Retention Basin and the 1987 WWTP improvements. The Phase II CSO control improvement projects addressed the CSOs that discharge into the James River Park Areas and the Falls of the James, which have a high potential for public contact. While approaching the completion of the Phase II CSO control improvements, the original CSO LTCP was re-evaluated to assess the completed work in light of the EPA's 1994 National CSO Control Policy and state-of-the-art technologies. The re-evaluation study final report, completed in 2002, identified a potential Phase III CSO control plan that addresses the remaining CSO outfalls in the City.

The re-evaluation study identified that after the completion of the Phase II CSO controls approximately 2,100 million gallons (MG) per year or 79% of the entire CSO volume will be discharged through the City's largest CSO outfall, Shockoe Creek, at a peak flow rate of 5,000 MGD. The study acknowledged that reliable disinfection of such a large flow rate and volume would be challenging and that inactivation efficiencies greater than 80% may be difficult to achieve and would require further investigations. The receiving water quality model showed that an 80% reduction of bacteriological loading would result in a significant improvement in water quality of the James River.

Under the recommendation of the re-evaluation report, the U.S. Army Corps of Engineers (USACE) and the City conducted a comprehensive disinfection pilot study between April 2003 and March 2005 to evaluate the feasibility of two technologies – ultraviolet (UV) irradiation and chlorination/dechlorination – to achieve a minimum of 80% or possibly higher disinfection efficiency at the Shockoe outfall.

2.2 PURPOSE AND SCOPE

The purpose of this report is to evaluate the feasibility and practicality of UV and chlorine to achieve 80% or higher disinfection efficiency at the Shockoe Outfall. This report presents the results of the disinfection pilot study. The conceptual level design criteria and cost effectiveness analysis for the potential UV and chlorination/dechlorination facilities at Shockoe outfall is also provided.

SECTION 3
CSO DISINFECTION WITH CHLORINE AND UV

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3.1 INTRODUCTION

The purpose of this section is to compare and contrast chlorine and UV in wastewater and CSO disinfection. The following topics will be included:

- Brief review of disinfection methods and means
- Disinfection mechanisms of chlorine and UV
- Dose relationships for chlorine and UV
- Effect of water quality parameters on disinfection efficiencies of chlorine and UV
- Overall comparison of chlorine and UV disinfection

3.2 REVIEW OF DISINFECTION METHODS AND MEANS

Various disinfection technologies are available via either chemical or physical mechanisms. Some of the common chemical disinfectants include gaseous chlorine, liquid sodium hypochlorite, chlorine dioxide, peracetic acid, and ozone. Ultraviolet (UV) radiation is the most commonly used physical disinfectant and has been receiving substantially more attention in recent years. Another physical disinfectant that is of increasing interest is ultrasound, which has been tested both as a disinfectant and as a pretreatment technology. Other than disinfection effectiveness, many factors, including toxic effects, safety precautions, ease of operation and maintenance, and regulations governing residuals standard, need to be considered for selection of a disinfectant.

Due to the safety concerns on the chlorine gas, it will be eliminated from consideration in this study. The disinfection technologies to be discussed include:

3.2.1 Sodium Hypochlorite

Sodium hypochlorite is more expensive but safer to handle than gaseous chlorine. The chlorination system should have adequate on-site storage capacity to feed the design dosage for the design overflow event. Extra volume may also be stored to allow for chemical degradation.

The advantage of using chlorine as CSO disinfectant is that it is a proven technology and has been applied with great success worldwide. The major disadvantages include: production of toxic byproducts such as trihalomethanes (THMs); toxicity of chlorine residual to aquatic life in receiving water; and chlorine may inadvertently enhance the growth of pathogenic microorganisms in receiving waters, since chlorine breaks large organic molecules into small organics that can be more readily used by coliform bacteria.

3.2.2 Chlorine Dioxide

Chlorine dioxide is applied to wastewater as a gas that is generated on-site using excess chlorine. Although it is relatively easy and economical to produce, chlorine dioxide is unstable and reactive and any transport is hazardous. Chlorine dioxide is effective at oxidizing phenols, but does not react with aquatic humus to produce trihalomethanes (THMs). However, any excess chlorine remaining from the generation of chlorine dioxide would react with THM precursors and form THMs. While chlorine dioxide will not react with wastewater to form chloramines, it can produce potentially toxic byproducts such as chlorite and chlorate. The use of chlorine dioxide in wastewater disinfection has been very limited in US.

3.2.3 Ozone

Ozone is a strong oxidizer and is applied to wastewater as a gas. Its use in CSO treatment facilities for wastewater disinfection is relatively new in the United States, and there are few facilities currently using ozone for disinfection. This can be potentially attributed to high initial capital costs associated with ozone generation equipment.

Ozone is equal or superior to chlorine in "killing" power, but it does not cause the formation of halogenated organics as does chlorination. Ozone requires much shorter contact time compared to chlorine. It degenerates into oxygen, which can elevate oxygen levels in treated water. It does not alter pH of water, and has taste and odor control properties.

Ozone must be generated on-site and the amount generated is dependent on the demand, therefore ozone is not currently considered practical for intermittent use in situations where the system would be frequently turned on and off or where there are wide fluctuations in flow rate and disinfection demand, such as in CSO treatment applications.

3.2.4 UV Irradiation

UV radiation is one example of electromagnetic radiation used for disinfection. UV disinfection incorporates the spectrum of light between 40 nm and 400 nm. Germicidal properties range between 200 and 300 nm, with 254 nm being the most lethal. The primary method for utilizing UV disinfection is to expose wastewater to a UV lamp. UV disinfection works by penetrating the cell walls of pathogenic organisms and structurally altering their DNA, thus preventing cell replication and function. No hazardous chemicals are produced or released while treating CSOs with UV. The UV disinfection efficiency is highly impacted by the transmittance and suspended solids concentration of the wastewater to be treated.

3.2.5 Ultrasonic

Ultrasound is any sound that lies above the limit of human perception (approximately 20 kHz). When ultrasonic waves are propagated through a liquid medium, cavitation (the formation and activity of bubbles or cavities in a liquid) is induced. Cavitation bubbles undergo two major types of growth: stable cavitation and transient cavitation. The motion of a pulsating stable cavitation bubble develops small scale eddying patterns called microstreaming. Significant hydrodynamic shearing stresses result at the boundaries between individual microstreams. Transient cavitation bubbles grow and then collapse violently, releasing the acoustic energy in the form of a spherical shock wave. Enormous temperatures and pressures exist in the shock wave. The temperature was found to be approximately 5,000 K, while the pressure can reach between 1,000 and 10,000 atm. The hot spot of the shock wave may induce many chemical reactions, such as hydrolysis of water molecules to H· and OH· radicals. The free radicals produced will participate in a number of oxidation and reduction reactions including the formation of hydrogen peroxide. In addition to acoustic cavitation, ultrasound also produces elevated temperatures in water as inefficient energy transfer results in sonic energy being dissipated into thermal energy. Through these mechanical, chemical and thermal mechanisms, ultrasound is able to cause damage to suspended cells.

3.2.6 Other Chemical Disinfectants

Besides the above-mentioned disinfectant, chemical agents that have been used as disinfectants include bromine, iodine, phenol and phenolic compounds, alcohols, heavy metals and related compounds, quaternary ammonium compounds and various alkalies and acids. Other chemical disinfectant, such as calcium hypochlorite and peracetic acid (CH_3COOOH) (PAA), also appear to be effective disinfectants.

Table 3-1 lists a wide range of characteristics of the most commonly used disinfectants. The following sections will be only focused on sodium hypochlorite and UV irradiation.

Table 3-1
Comparison of Ideal and Actual Characteristics of Commonly Used Disinfectants [1]

Characteristics	Properties/response	Sodium Hypochlorite	Chlorine Dioxide	Ozone	UV Irradiation
Availability	Should be available in large quantities and reasonably priced	Moderately low cost	Moderately low cost	Moderately high cost	Moderately high cost
Deodorizing Ability	Should deodorize while disinfecting	Moderate	Moderate	High	N/A
Homogeneity	Solution must be uniform in composition	Homo-geneous	Homo-geneous	Homo-geneous	N/A
Interaction with extraneous material	Should not be absorbed by organic matter other than bacterial cells	Active oxidizer	Active oxidizer	Oxidizes organic matter	Absorbed by specific organic compounds
Noncorrosive and nonstaining	Should not disfigure metals or stain clothing	Corrosive	Corrosive	Highly corrosive	N/A
Nontoxic to higher forms of life	Should be toxic to microorganisms and nontoxic to humans and other animals	Toxic	Toxic	Toxic	Toxic at high dosages

Characteristics	Properties/response	Sodium Hypochlorite	Chlorine Dioxide	Ozone	UV Irradiation
Penetration	Should have the capacity to penetrate through surfaces	High	High	High	High safety
	Should be safe to transport, store, handle, and use	Moderate risk	Moderate risk	Moderate risk	Low risk
Solubility	Must be soluble in water or cell tissue	High	High	Low	N/A
Stability	Loss of germicidal action on standing should be low	Slightly unstable	Slightly unstable	Unstable, must be generated as used	Must be generated as used
Toxicity to microorganisms	Should be highly toxic at high dilutions	High	High	High	High
Toxicity at ambient temperatures	Should be effective in ambient temperature range	High	High	High	High

(1) Adapted, in part, from WERF report, *Comparison of UV Irradiation to Chlorination: Guidance for Achieving Optimal UV Performance* (1995).

3.3 MECHANISMS OF DISINFECTION

The main mechanisms that have been proposed to explain the action of disinfectants include: damage to the cell wall; alternation of cell permeability; alteration of colloidal nature of the protoplasm; enzyme inhibition; and damage to the cell deoxyribonucleic acid (DNA) and ribonucleic acid (RNA).

3.3.1 Disinfection Mechanisms with Chlorine

Many theories have peen set forth to explain the germicidal effects of chlorine and its related compounds. These theories include: oxidation; reactions with chlorine; protein precipitation; modification of cell wall permeability; and hydrolysis and mechanical disruption. Despite the fact that all of the above mechanisms may be operative, the predominant mechanism will depend on the microorganism in question, its life history, the chlorine compound used and the wastewater characteristics.

3.3.2 Disinfection Mechanisms with UV Irradiation

The germicidal effectiveness of UV irradiation is derived from its ability to penetrate the cell wall and damage links in the DNA molecules, resulting in the cell's inability to replicate. This process is generally referred to as "inactivating" the microorganism. UV is most effective in the far UV (UVC) region of the electromagnetic spectrum, between 230 and 290 nm, generally corresponding to the absorbance spectrum of nucleic acids. The optimum germicidal wavelengths appear to be in the vicinity of 255 to 265 nm.

3.4 DOSE RELATIONSHIPS FOR CHLORINE AND UV

The dose of the disinfecting agent to which the microorganisms are exposed will affect the germicidal effects of both chlorine and UV. The definition of dose for chlorine and UV disinfection are discussed below with the consideration of other factors.

3.4.1 Dose of Chlorine

When all other physical parameters influencing the chlorination process are held constant, the germicidal efficiency of chlorine will depend primarily on the concentration of chlorine added (C) and the contact time (t). Increasing either C or t and simultaneously decreasing the other one will achieve approximately the same degree of disinfection. Hence, the efficiency of disinfection may be expressed as a function of the product of C and t.

3.4.1.1 *Chlorine Concentration*

Hypochlorous acid (HOCl), hypochlorite ion (OCl^-) and monochloramine (NH_2Cl) are the principal chlorine compounds used as disinfectant. For a given contact time or residual, the germicidal efficiency of hypochlorous acid is significantly greater than that of either hypochlorite ion or monochloramine. But given enough contact time, these disinfectants can be of the same effectiveness.

As added into the wastewater, the chlorine reacts with ammonia and organic matter to form chloramines and chloroorganic compounds. Adding more chlorine oxidizes some of the chloroorganic compounds and chloramines; monochloramines are converted to dichloramines and trichloramines. As more chlorine is added, a point is reached where the residual chloramines and the chloroorganic compounds are reduced to a minimum value, and a free chlorine residual results with the further addition of chlorine. This point is known as the "breakpoint". The term "breakpoint chlorination" refers to the process whereby enough chlorine is added to the wastewater to obtain a free chlorine residual.

3.4.1.2 *Contact Time*

Since chlorine can react with nitrogenous compounds in wastewater and to obtain free hypochlorous acid beyond the breakpoint is not economically feasible in many situations, the importance of contact time cannot be overemphasized. For identical contact time, a batch or plug-flow reactor can be more effective than a completely mixed reactor. In most WWTPs, plug-flow reactors are used.

3.4.1.3 *Initial Mixing*

Initial mixing of the chlorine solution and the wastewater is of equal importance. In practice, effective initial mixing of chlorine can be achieved in many different ways including: in hydraulic jumps in open channels; in Venturi flumes; in pipelines; within pumps; and with static mixers or in vessels with the aid of mechanical mixing devices. Ideally, initial mixing should take place in a fraction of a second.

3.4.2 Dose of UV Irradiation

The dose of UV irradiation must be sufficient to achieve the desired germicidal effect. The quantity of UV dose can be defined as follows:

$$D = I \times t$$

Where:

D = UV dose, $mW\text{-}s/cm^2$
I = average intensity of the UV energy, mW/cm^2
t = exposure time, s

The dominant commercial source of UV light for disinfection applications is the mercury vapor, electric discharge lamp, with "low-pressure" or "medium pressure" configurations. Both conventional low-pressure-low intensity (LPLI) lamps and recently developed low-pressure-high-intensity (LPHI) lamps (with output 1.5-2.0 times higher than that of LPLI) generate UV output that is nearly monochromatic at a wavelength of 254 nm. The medium-pressure lamps generate polychromatic UV lights, and have many times the total UVC output of the conventional low-pressure lamp, however, only about 7 to 15 percent of its input energy is converted to germicidal light in the vicinity of 254 nm.

Currently, chemical actinometry, biological assays and mathematical models are the three principal methods used in estimating UV dose or intensity. The lack of standardization in determination of UV dose has made it difficult to compare the results from different studies and created problems for designers. Chemical actinometry and biological assays can offer an estimate of UV dose, but mathematical models offer an estimate of UV intensity, which can be used to calculate UV dose with an estimate of average exposure time. Biological assays have been used in estimating UV dose in field situations, whereas the usage of chemical actinometry in field situation has been limited due to the significant effects of procedural variations and the cost of the procedure. The bioassay dose is determined through a bench-scale test, known as the "collimated beam test", under highly controlled conditions. More information about the collimated beam test can be found in **Section 4.1.3** of this report.

3.4.2.1 *UV Intensity*

Point source summation (PSS), also called the finite length lamp is commonly used to determine average UV intensity in a UV disinfection system. In the PSS method, the average UV intensity for a particular reactor geometry and lamp configuration is determined as a function of the UV transmittance of the water to be disinfected. The cylindrical UV lamps within a reactor are considered as a finite series of point sources radiating in all directions and the light from every point source is assumed to be spread over spheres. Hence, the intensity at any point can be calculated by summing the intensities at the point from all point sources in the system.

Although the PSS method is relatively straightforward by using computer code, it has limitations. One of the limitations is that the PSS model was based on particle-free water but this assumption is not valid in most wastewater effluents. The other limitation is the intensity obtained from the PSS method must be considered with the estimate of exposure time to determine UV dose.

3.4.2.2 *Exposure Time*

Exposure time in continuous flow UV disinfection system depends on the flow rate, the number of UV banks used and the overall reactor configuration and operation. Typical mean exposure time for horizontal plug-flow UV disinfection system with a single bank is on the order of 5 to 7 seconds. In UV system design, the exposure time is accounted for by the parameter "lamp loading", which is defined as flow rate per lamp (gpm/lamp) or flow rate per lamp output (gpm/watt).

3.5 EFFECTS OF WATER QUALITY PARAMETERS ON DISINFECTION

3.5.1 Effect of Water Quality Parameters on Chlorine Disinfection

3.5.1.1 *Wastewater Compounds*

The characteristics of the compounds in wastewater will affect the efficiency of the chlorine disinfection in the following ways: in the situation where interfering organic compounds are present, the total chlorine residual cannot be used as a reliable measure to assess the germicidal efficiency of chlorine; the degree of interference of the compounds depends on their functional groups and their chemical structure; and to achieve low bacterial counts in the presence of interfering organic compounds, addition chlorine and longer contact time are required.

3.5.1.2 *Nitrogenous Compounds*

Organic nitrogen, ammonia nitrogen, nitrite nitrogen and nitrate nitrogen are the principal nitrogenous compounds that might be present in wastewater. The effects of ammonia on efficiency of chlorine disinfection are exhibited in the form of chloramines.

3.5.1.3 *Suspended Solids*

Suspended solids (SS) is another factor that affects the efficiency of chlorine disinfection. In the presence of SS, the disinfection process is controlled by two different mechanisms. The initial bacterial kill is of individual bacteria and bacteria in small clumps, and the subsequent bacterial kill is a function of the particle size.

3.5.2 Effect of Water Quality Parameters on UV Disinfection

The performance of UV disinfection also depends on the wastewater parameters, such as wastewater transmittance, suspended solids concentration and constituents that can precipitate on UV lamps.

3.5.2.1 *UV Transmittance*

The ability of a wastewater to transmit UV light is measured with a spectrophotometer (typical path length of 1cm) using the same wavelength as is produced by the UV lamps (253.7nm). Some inorganic and organic compounds and SS can affect the percent transmittance by absorbing or scattering UV light. As the transmittance of a wastewater decreases, the average UV intensity within the UV reactor decreases. Of the inorganic compounds that affect the percent transmittance, iron is considered to be the most important with respect to UV absorbance. Iron can decrease the intensity of UV light in three ways: dissolved iron can absorb

UV light directly; iron will absorb onto suspended solid, bacterial clumps and other organic compounds which can prevent the UV light from penetrating the particle; and iron can precipitate onto the quartz tubes that protect the UV lamps. Coloring agents, organic dyes and humic substances are the principal organic compounds found in wastewater in concentration high enough to affect the transmittance significantly.

3.5.2.2 *Suspended Solids*

Suspended solids can have several effects on UV disinfection: shading limits the exposure of individual and particle associated bacteria to UV light; scattering and absorption of UV radiation limits the exposure of particle associated bacteria to UV light; and incomplete penetration of UV light limits the exposure of bacteria embedded in large particles. The shading has not been a problem in well-designed UV reactor with lateral dispersion. Scattering has also not been considered to be a significant factor as the scattered light is still germicidal, only with decreased intensity due to longer travel distance.

3.5.2.3 *Constituents that Foul UV Lamp Quartz Sleeves*

The UV lamps are sheathed in quartz sleeves and placed directly in the wastewater stream, configured in a symmetrical array, and oriented horizontally or vertically. Over time, the surface of the quartz sleeves that are in contact with the water starts collecting organic and inorganic debris (e.g., iron, calcium, silt) causing a reduction in sleeve transmissibility. This is usually referred to as "fouling". The conventional LPLI lamp quartz sleeves are cleaned in an acid bath (e.g., phosphoric acid) periodically; the LPHI systems are usually equipped with an automatic mechanical wiper (Teflon-ring or stainless steel scrapper). The medium pressure lamp sleeves are more rapidly fouled due to higher operating temperature, thus generally cleaned with automatic mechanical/chemical wiper. Fouling and subsequent cleaning of the UV tubes can be significant cost items that must be considered in a cost analysis of UV disinfection.

3.6 OVERALL COMPARISON OF CHLORINE AND UV DISINFECTION

At present, wastewater is most commonly disinfected with chlorine and UV disinfection has been used as an alternative to chlorine in many parts of the U.S.

Chlorine is an effective disinfectant and chlorine disinfection is a well-established technology, which traditionally is relatively inexpensive and can also supply residual effect. However, chlorine residual and various chlorinated by-products in wastewater can have long-term adverse effects on the beneficial uses of receiving waters. To minimize the potential toxic effects, it has been necessary to dechlorinate wastewater disinfected with chlorine.

UV light is also an effective disinfectant with no residual toxicity and improved safety and it is more effective than chlorine in inactivating most viruses, spores and cysts. Its major advantages include short contact time, insensitivity to pH and temperature, small footprint, no formation of by-products, no toxic disinfectant residual, no on-site chemical storage, and flexible dosage control. However, UV disinfection cannot supply residual effect and it is relatively expensive. Also there is no immediate measure to assess whether disinfection is successful.

SECTION 4
DISINFECTION PILOT STUDY

Greeley and Hansen LLC
June 2005

4.1 UV DISINFECTION PILOT STUDY

4.1.1 Selection of UV Testing Units

A large variety of UV disinfection systems were evaluated and two systems, WEDECO UV Technologies TAK55 and Trojan Technologies System UV4000, participated in the pilot study. The major features of the two pilot units are summarized in **Table 4-1.** The photographs of the pilot units are shown on **Figure 4-1**.

Table 4-1
UV Disinfection Pilot Units

Parameter	WEDECO TAK55	Trojan UV4000
Lamp	Low pressure high intensity	Medium pressure high intensity
Lamp Arc Length	56 inch (1430 mm)	10 inch
Center-to-Center Spacing of Lamps	3.94 inch (100 mm)	5 inch
Lamp Operating Temperature	110 °C	600-800 °C
Lamps/Banks	24/2	8/2
Input Power	275 watt/lamp	2,800 watt/lamp
Output Power Range	100-50% of full power	100-30% of full power
Warm-up Time	~10 min	~10 min
Flow Capacity	Up to 400 gpm (0.58 MGD)	Up to 3 MGD
Reactor	Open channel	Closed vessel
Cleaning Mechanisms	Mechanical wiper	Mechanical/chemical wiper
UV Intensity Sensor	One per bank	None
Reactor Level Control	Fixed weir	Fixed weir

Figure 4-1
Photographs of UV Disinfection Pilot Units

(a) WEDECO Ideal Horizons TAK55 Pilot Unit

(b) Trojan Technologies System UV4000 Pilot Unit

4.1.2 UV Disinfection Pilot Plant

Figure 4-2 shows the flow diagram of the existing Shockoe Retention Basin. Normal dry weather flow from Shockoe Creek CSO area will flow through the Shockoe Arch Sewer and the Shockoe Diversion Structures (SDS) to the 96" Shockoe Creek Interceptor, and ultimately to the WWTP for treatment. During wet weather events, the combined sewer flows will come down through the Shockoe Arch and Box sewers and build up in the SDS. At the same time, the WWTP will pump the water out of the system up to its wet weather treatment capacity (75 MGD). When the water level in the SDS approaches the crest elevation of the Bascule Gates, the roller gates will open and allow the flow into the SRB through three Diversion Conduits. Once the basin is filled up, the roller gates close and excessive flow will spill over the Bascule Gates, then the Overflow Weir and discharge into the James River. After the storm event, the WWTP will keep pumping at 75 MGD until the SDS and SRB are emptied. The Crossover Chamber is for the release of storm water inside the floodwall.

The 2002 CSO re-evaluation study proposed to expand the SRB by 15 MG, and convert it to a flow-through storage facility. The existing CSO outfall will be relocated to the eastern end of the expanded basin, and disinfection will be provided for the overflows prior to discharge into the James River. In order to better simulate this future condition, the UV disinfection pilot plant was set up on the Diversion Conduits to catch the "first flush" combined flows into the basin.

Figure 4-2
Site of UV Disinfection Pilot Plant

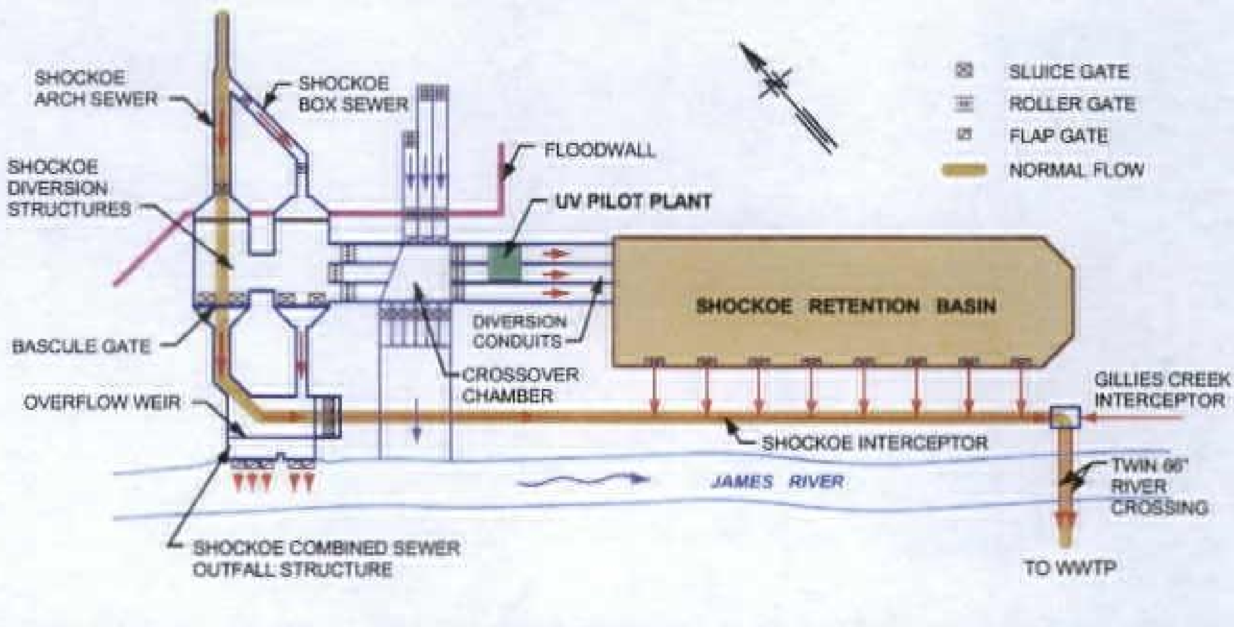
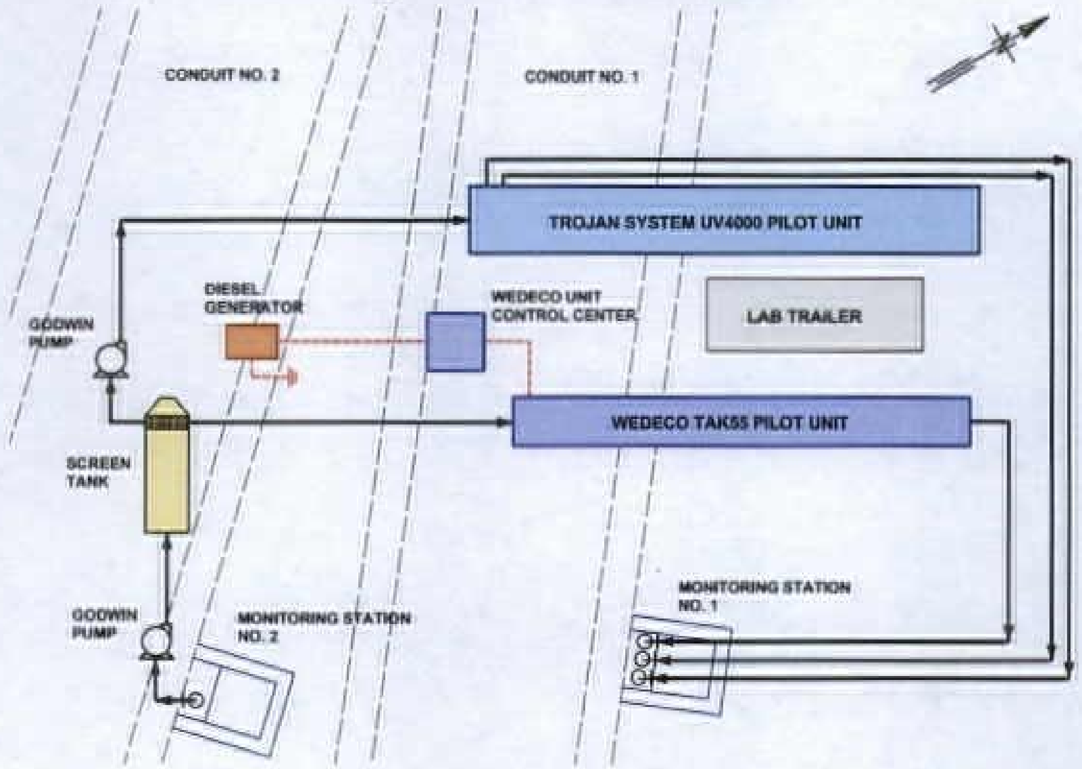


Figure 4-3 shows the flow diagram of the UV pilot plant. The raw CSO water was pumped out of Diversion Conduit No. 2 through the Monitoring Station to a screen tank, where a 1¼ " bar screen was used to keep the large debris from getting into the pilot units. Portion of the flow was fed into the WEDECO pilot unit by gravity, and discharged back into Diversion Conduit No. 1 after UV disinfection. A second pump was used to provide influent to the Trojan pilot unit, and

the UV treated effluent was also discharged to Diversion Conduit No. 1 through two effluent pipes. The power to both systems were provided by diesel generators. Throttle valves and magnetic flow meters were installed on the influent pipes for flow control and measurement.

Figure 4-3
Flow Diagram of UV Disinfection Pilot Plant



4.1.3 UV Testing Protocol

The UV testing protocol was developed based on the U.S. EPA's Environmental Technology Verification program publication "*Generic Verification Protocol for High-Rate, Wet-Weather Flow Disinfection Applications*" (U.S. EPA 2000), and modified for each specific UV pilot unit. A quality assurance/quality control (QA/QC) project plan was developed as part of the testing protocol. The UV testing program comprised three testing elements: bench-scale collimated beam test (CBT), UV pilot performance test, and fouling/wiper efficiency test.

4.1.3.1 *Collimated Beam Test*

The collimated beam test is a standard bench-scale test to develop the UV dose-response curve for a given organism. It can also be used to determine the UV dose delivery (bioassayed dose) in an actual UV reactor. Comparing different reactor performance using the collimated beam test provides a basis for comparing different technologies as it removes the potential bias found in theoretical intensity models (e.g., intensity models assume perfect hydraulics or ideal mixing).

The CBT is conducted using a collimated beam apparatus that consists of a low-pressure lamp arranged horizontally with a long vertical tube allowing the UV light to irradiate down into sample dish with a uniform intensity field. The intensity field at the level of the sample dish is measured with a radiometer, and samples are irradiated for different time periods to obtain different applied doses.

During this study, composite influent CSO samples were collected during the UV pilot performance tests and shipped to WEDECO's laboratory in Charlotte, NC for collimated beam tests. Collimated beam tests were also performed at Center of Environmental Studies of Virginia Commonwealth University using the collimated beam apparatus provided by Trojan Technologies. Water quality parameters such as UVT, TSS and PSD were measured, and dose-response curves (log reduction vs. UV dose) were developed for fecal coliform and *E. coli*.

4.1.3.2 *UV Pilot Performance Test*

The purpose of the pilot performance test is to evaluate the effect of water quality and system operational parameters (flow rate, power setting) on the system performance, and to establish the UV design dosage rate and number of lamps required for the full-scale system.

The UV systems were operated during wet-weather events when combined sewer overflow was available from the Shockoe Retention Basin. The basin must be emptied in 2 days after wet weather flow subsides, therefore the duration of each testing event normally ranged between 1 to 3 days.

The pilot system was run at a variety of flow rates and ballast power settings to achieve a series of UV doses at which time duplicate samples were taken before and after the UV reactor and analyzed for fecal coliform and *E. coli* concentration. Samples were also taken for analysis of UVT and TSS for each combination of flow rate and power setting. Composite samples were also collected for collimated beam tests. To simulate the worst water quality (25% UVT, >100 mg/L) that has been observed for Shockoe CSOs, calcium lignosulfonate (LSA) and/or bentonite clay was added into the CSO influent to decrease the UVT or increase the TSS concentration.

The performance tests were conducted to evaluate the system under "new" and "clean" conditions, i.e., without lamp aging or fouling effect. New lamps and quartz sleeves were used. The quartz sleeves were cleaned manually with Lime-A-Way (for WEDECO system) or using chemical/mechanical wiper with Acticlean Gel (for Trojan system) several times prior to each series of test runs, and the automatic wipers were operated at the maximum cleaning frequency during the test to keep the quartz sleeves clean.

4.1.3.3 *Fouling/Wiper Efficiency Test*

The objective of the fouling/wiper efficiency test is to measure the effectiveness of the cleaning mechanisms to control fouling, and to provide bases for determining fouling factor and wiper operation modes.

Due to the intermittent occurrence and highly variable water quality of CSOs, it is difficult to bacterially evaluate the direct effect of fouling on disinfection efficiency, i.e., by comparing bacteria reduction with and without cleaning mechanisms in operation. Each manufacturer recommended testing protocol that was specific to their pilot unit.

WEDECO pilot unit has a UV intensity sensor installed in one lamp module per bank. Therefore, WEDECO recommended the fouling or wiper efficiency be evaluated using the UV intensity reading. During a fouling testing event, the quartz sleeves were manually cleaned with Lime-A-Way, then CSO was continuously pumped through the pilot unit at a relatively low flow rate (100 gpm) for 2-3 days. Both banks were operated at 100% power to maximize the potential fouling effect. The wiper system on Bank A was operated at two wiping cycles per 50 minutes (based on 30,000 guaranteed wiping cycles through the guaranteed lamp life of 12,000 hours, if the wiper rings are replaced along with the lamps), whereas the wiper system on Bank B was left dormant. At the end of testing event, the wiper system on Bank B was activated and the UV intensity was recorded after 3 wiping cycles to evaluate the effectiveness of the wiper to remove the deposits on the quartz sleeves. The UV intensity and UVT was recorded every six (6) hours. The following water quality samples were collected every hour to combine as 6-hour composite samples: TSS, total and dissolved iron, magnesium, manganese, hardness (calcium), oil and grease. Since the water quality to Bank A and Bank B was exactly the same, the difference of UV intensity readings between the two banks can be used to evaluate the wiper efficiency.

The Trojan pilot unit did not have UV intensity sensors installed in the reactor. The wiper efficiency was evaluated by comparing the transparency of the quartz sleeves before and after the entire pilot testing period using a modified spectrophotometer. The transparency of the quartz sleeves was measured under controlled conditions at Trojan's lab. This method enabled the fouling condition and overall wiper performance to be evaluated over a 7-month period.

The conditions of the quartz sleeves for both pilot units were visually observed and documented throughout the study.

4.1.4 Sample Analysis

All fecal coliform and *E. coli* sample analyses were performed at the Center of Environmental Studies of Virginia Commonwealth University. Fecal coliform and *E. coli* samples were analyzed in accordance with *The Standard Methods for the Examination of Water and Wastewater*, 20th ed., Method 9222 D, and EPA Method 1103.1 (mTEC agar, EPA-821-R-02-020). UVT was measured on site using single-wavelength (254 nm) spectrophotometers with 1-cm quartz cuvette provided by Trojan and WEDECO. PSD analysis was performed at Trojan's Analytical Services, London, Ontario, Canada. All other water quality parameters, including TSS, iron, magnesium, manganese, hardness, oil and grease, were analyzed by a certified commercial laboratory, James R. Reed & Associates, Newport News, Virginia.

4.1.5 Results and Discussions

The Shockoe CSO water quality characteristics during the 12-month testing period are summarized in **Table 4-2**. The bacteria concentrations as well as UVT and TSS were highly variable from test to test. The mean particle size was consistently greater than 30 microns with 44-62% of the particles greater than 30 microns, which suggested that particles generally had an adverse impact on the UV disinfection efficiency.

Table 4-2
Summary of UV Disinfection Testing

Parameter	Wedeco TAK55	Trojan UV4000
Testing Dates	April 2003 – March 2004	September 2003 – April 2004
UVT (1)	20-61%	24-55%
TSS	10-114 mg/L; Average 52 mg/L	15-123 mg/L; Average 55 mg/L
Mean Particle Size	45-70 microns	
Fecal Coliform	230,000-6,130,000 cfu/100 mL; Average 2,100,000 cfu/100 mL	
E. Coli	86,700-2,100,000 cfu/100mL; Average 766,000 cfu/100 mL	

(1) Raw CSO UVT varied from 30% to 61%, with average of 45%.

4.1.5.1 *Determination of Bioassayed UV Dose – Collimated Beam Tests*

There were three (3) collimated beam tests performed by WEDECO lab and eight (8) CBTs performed using Trojan's collimated beam apparatus. The WEDECO CBTs were conducted only on fecal coliform, whereas Trojan CBTs were conducted on both fecal coliform and *E. coli*. The dose-response curves are presented on **Figure 4-4**.

Since UVT has been accounted for during the collimated beam tests, the variability of the dose-response curves is dependent upon other water quality parameters such as TSS and particle size. It is generally believed that inactivation of the free-living bacteria occurs at lower UV dose; the particle associated bacteria are more difficult to inactivate thus requiring higher UV dose, which causes the plateau of the dose-response curves. **Figure 4-4** shows that the curves start to plateau at an approximate UV Dose of 15 mWs/cm^2.

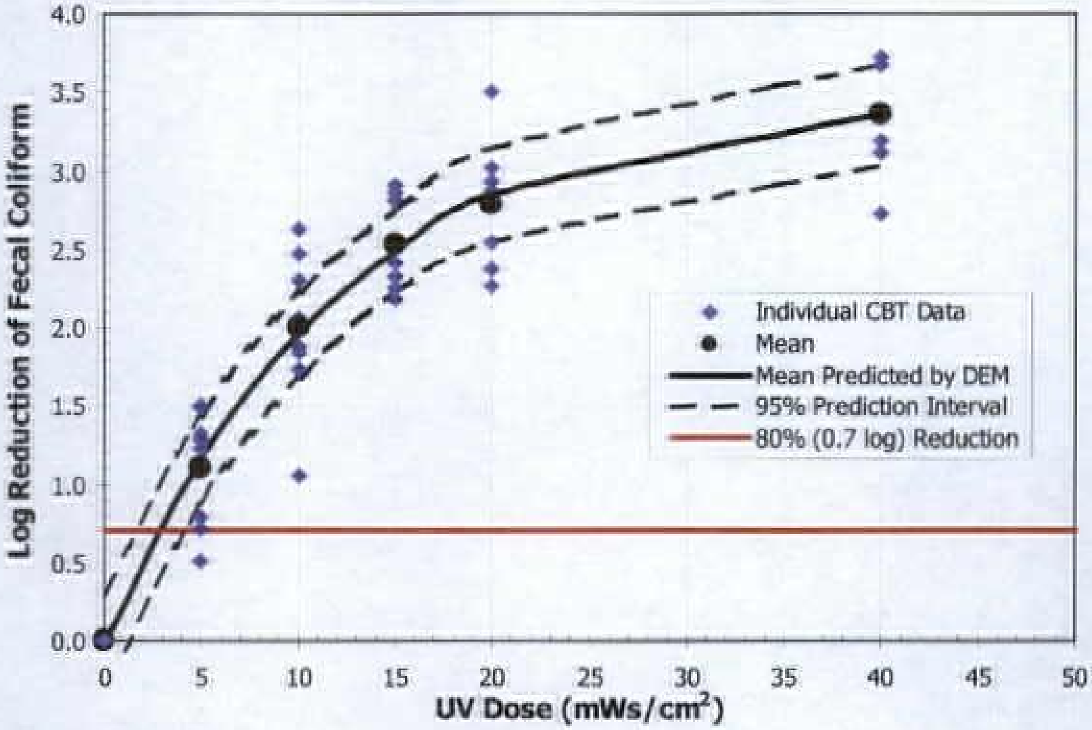
Trojan has developed a double exponential model (DEM) to mathematically describe the dose-response curve from the collimate beam test. The model is expressed by the following equation:

$$\text{Log Reduction} = ae^{-bD} + ce^{-dD}$$

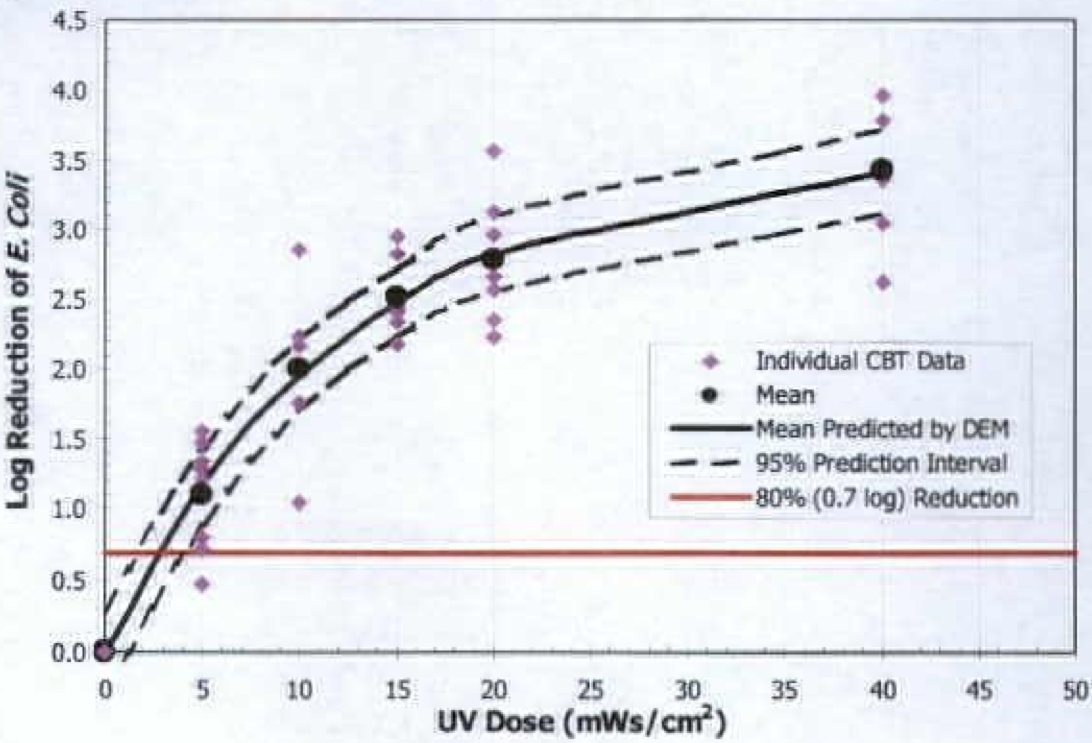
where, a, b, c and d are empirical constants, and D is bioassayed dose in mWs/cm^2. For each day specific CBT, a DEM was developed, then the delivered UV dose in the reactor corresponding to the log reduction from each test run on that testing day was determined. **Figure 4-4 (a)** and **(b)** show the mean and 95% confidence interval predicted by the DEM.

Figure 4-4
Dose-Response Curves from Collimated Beam Tests

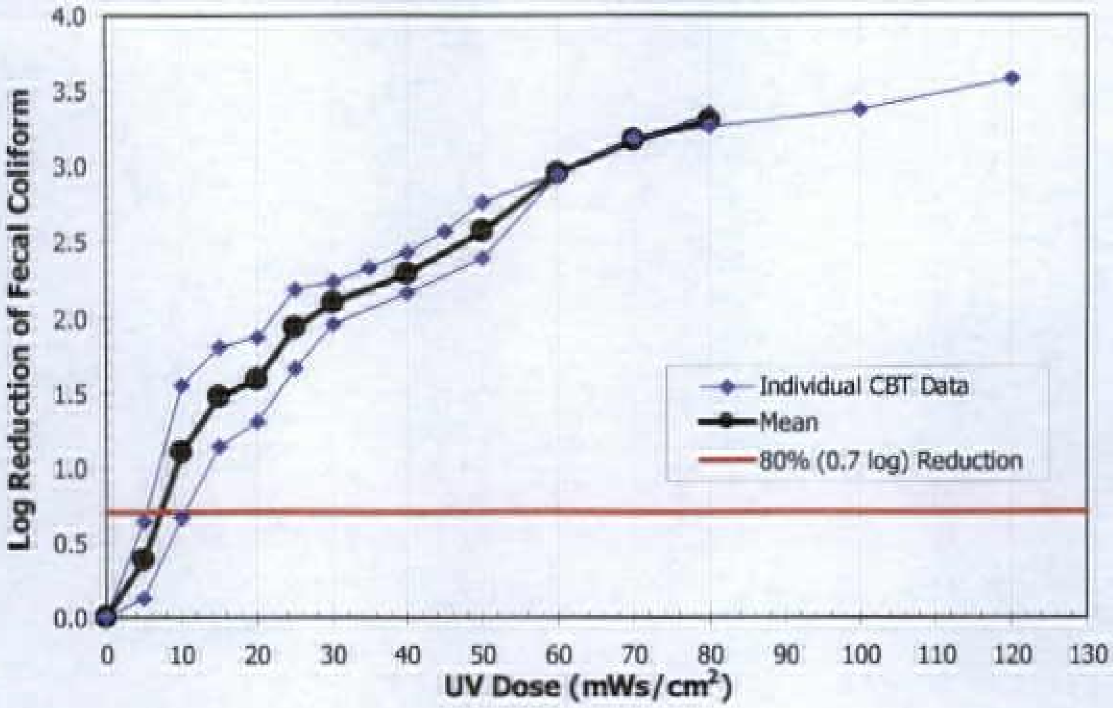
(a) Trojan CBTs – Fecal Coliform



(b) Trojan CBTs – *E. Coli*



(c) WEDECO CBTs – Fecal Coliform



4.1.5.2 *UV Pilot Performance Tests*

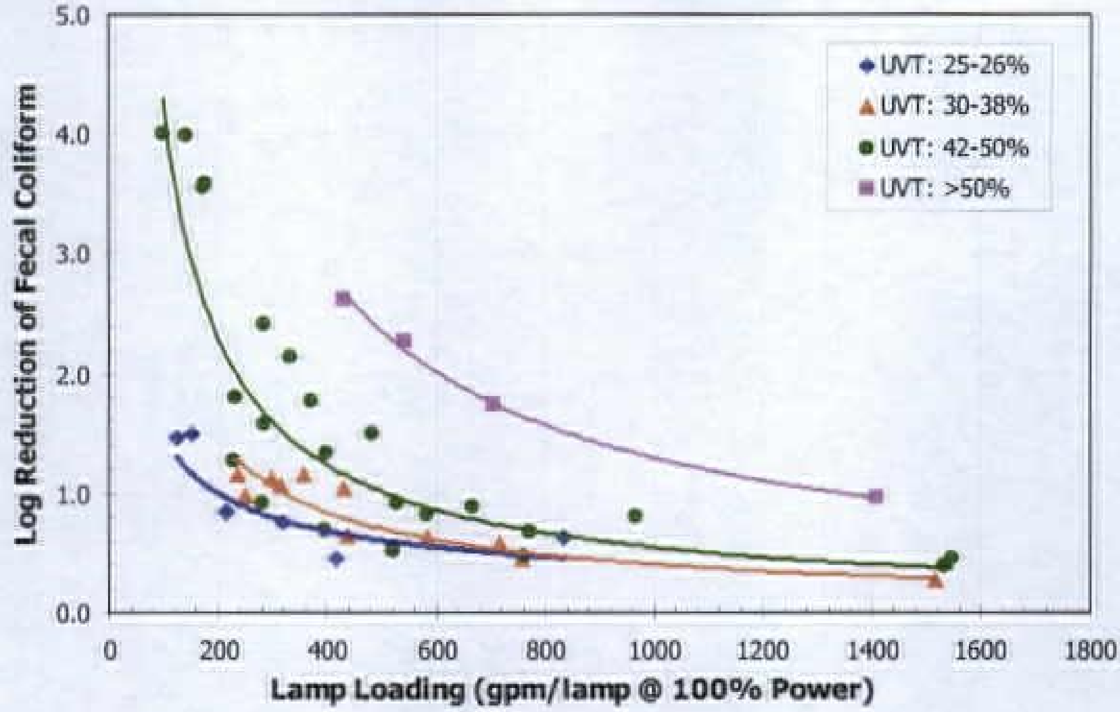
There were 16 sets of pilot system performance tests (73 test runs) conducted for WEDECO unit and 11 sets of tests (50 test runs) for Trojan unit, including four (4) sets of LSA tests (23 test runs) and one (1) set of bentonite clay test (6 test runs) for WEDECO unit and one (1) set of LSA test (6 test runs) for Trojan unit.

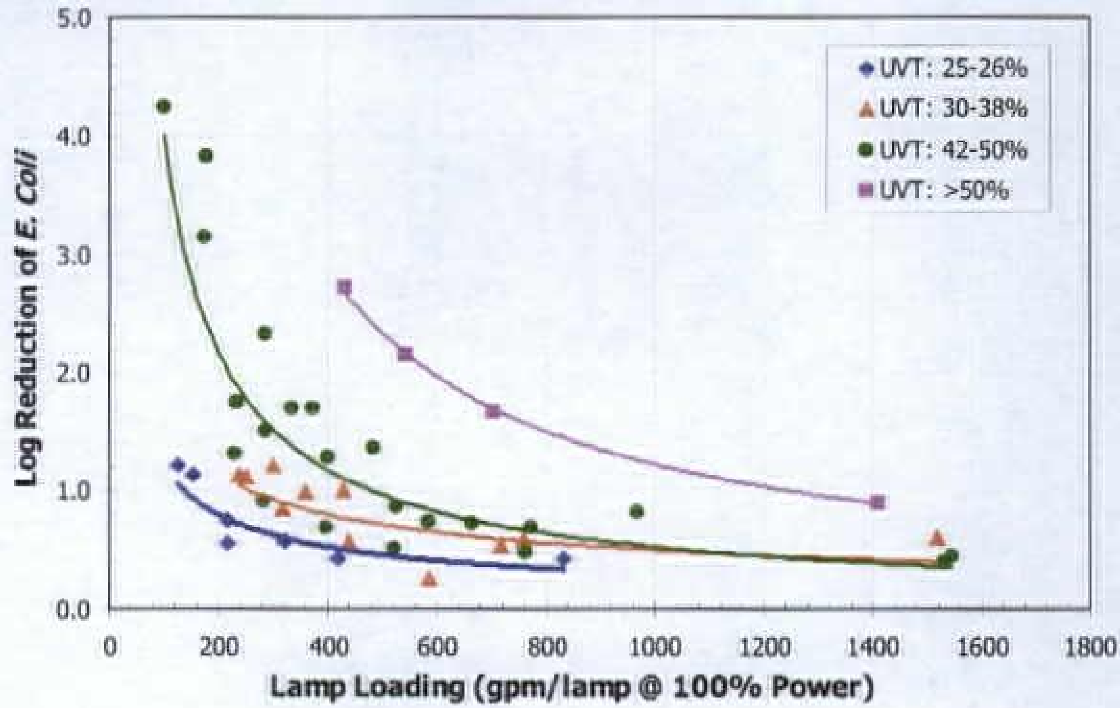
As described above, UV disinfection efficiency is dependent upon several variables, including flow rate, ballast power setting, water quality (UVT, TSS and PSD), lamp aging and fouling. Since lamp aging and fouling factors had been "eliminated" during the performance tests, and the effect of PSD is difficult to quantify, the following analysis will only consider four variables: flow rate, power setting, UVT and TSS. These variables are independent of each other except for UVT and TSS; the latter along with other water constituents has an impact on the former.

Figure 4-5 shows the log reduction of fecal coliform and *E. coli* as a function of lamp loading from the pilot testing. The lamp loading (flow/lamp) has been normalized to equivalent 100% power setting. For example, with flow rate of 1600 gpm, and both banks (8 lamps) operated at 50% ballast power, the adjusted lamp loading is calculated as: (1600 gpm/8)/50% = 400 gpm/lamp at 100% power. It should be noted that **Figure 4-5** only intends to show the trend of the data; the design parameters should be determined based on multivariable modeling analysis (described later in details).

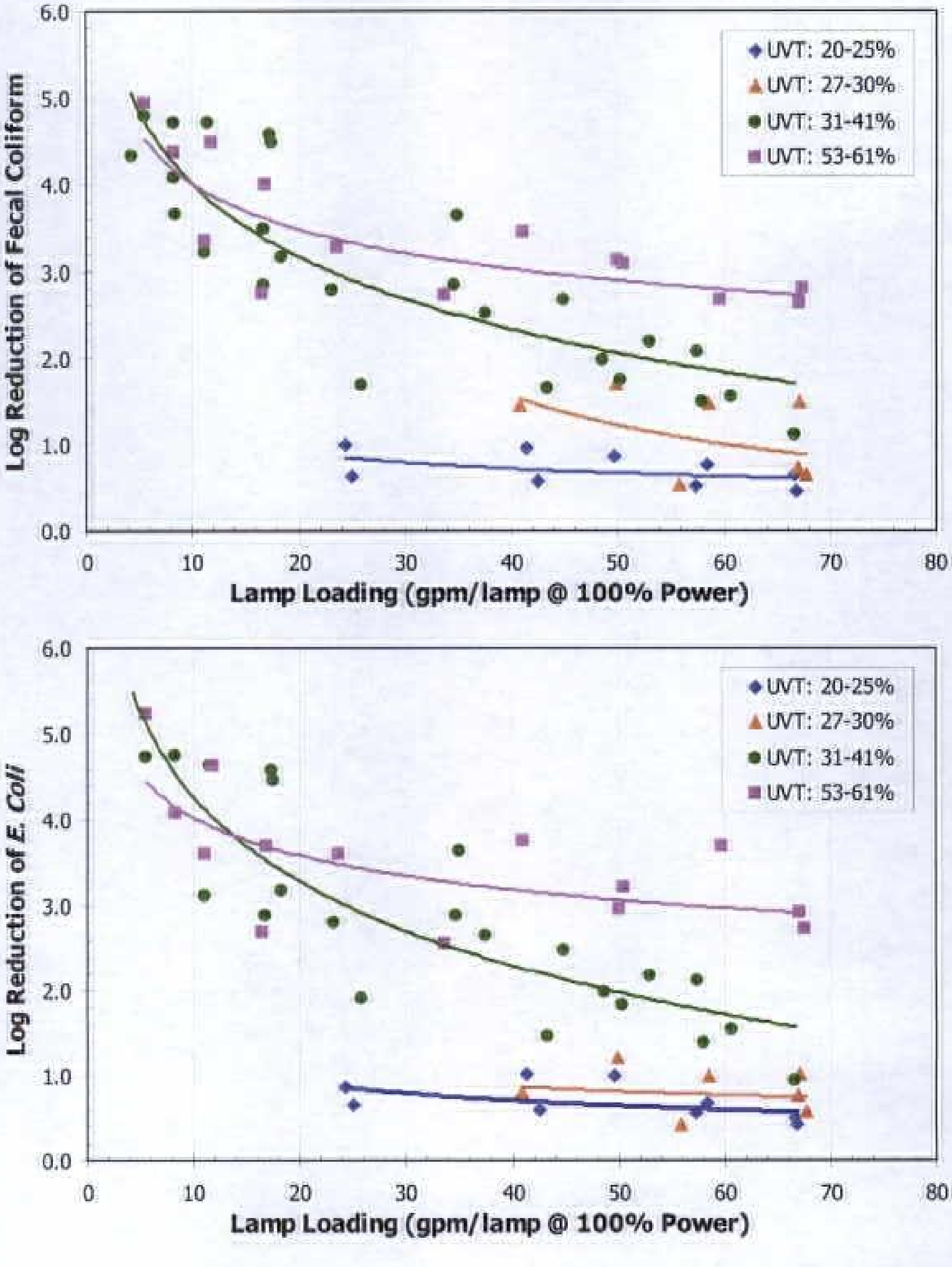
Figure 4-5
Log Reduction versus Lamp Loading from Pilot Performance Tests

(a) Trojan Pilot Unit





(b) WEDECO Pilot Unit



As shown in **Figure 4-5(a)**, log reduction of fecal coliform or *E. coli* increases as UVT increases at the same lamp loading. As water quality gets better (higher UVT), the lamp loading to achieve a given reduction increases significantly, resulting in less number of lamps required. For a given water quality, improving disinfection efficiency would require many more lamps. The log reduction appears sensitive to a change of lamp loading at lower lamp loading ranges. Similar trends are shown on **Figure 4-5(b).**

Similar analysis was conducted for TSS, but no consistent trend was observed. Bentonite clay was added into the CSO influent in an attempt to evaluate the effect of solids concentration. It was found that bentonite clay would also decrease the UVT of the CSO (20 mg/L of clay caused about 3% reduction in UVT). A collimated beam test conducted on the Shockoe CSO with and without the addition of bentonite clay (112 mg/L TSS vs. 38 mg/L TSS) showed that adding to solids concentration slightly increased bioassayed UV dose for a given log reduction; this effect was not as significant at lower UV dose range (less than 5 mWs/cm^2). The particle effect is complicated and must be evaluated using both TSS and PSD information.

The pilot performance testing data were further analyzed using multivariable linear regression (MLR) models. The models were developed for both fecal coliform and *E. coli* data; however, only the fecal coliform MLR models are presented here as the water quality model that uses the MLR model as input (described in **Section 5**) was calibrated based on fecal coliform data.

4.1.5.3 *Multivariable Linear Regression Models*

4.1.5.3.1 **Trojan Pilot Unit**

For most of the Trojan pilot testing events, composite samples were collected for collimate beam tests, therefore the bioassayed (delivered) UV doses can be determined using each specific dose-response curve (described by double exponential model) for these test runs.

Two MLR models were developed for the Trojan pilot unit, both having log(flow/lamp/bank), log(power), and log(UVT) as independent (X) variables. The first model uses log(delivered dose) as dependent (Y) variable, and has the following form:

Log(delivered dose)
= -0.9512 – 2.1909 log(flow/lamp/bank) + 1.0002 log(power) + 3.3181 log(UVT); R^2 = 0.86

where, "flow/lamp/bank" is calculated as flow rate (gpm) divided by number of lamps per bank (4), which ranges from 200 to 464 gpm/lamp; "power" is the relative ballast power setting, varying from 30 to 100; "UVT" ranges from 24 to 52.

Initial analysis also included log (TSS) in the model. However, this variable turned out to be statistically insignificant at 95% confidence level (P-value > 0.05). The effect of suspended solids on the UV system performance is related to both TSS concentration and particle size distribution. In this study, the TSS concentration as an independent variable did not exhibit a statistically significant quantitative correlation with the log reduction, although qualitatively higher TSS concentration would impair UV system performance provided other water quality parameters being equal. The effect of TSS will be further investigated during the development of the Phase III CSO Program Project Plan.

The second model uses log(log reduction) as dependent variable. The model has the following form:

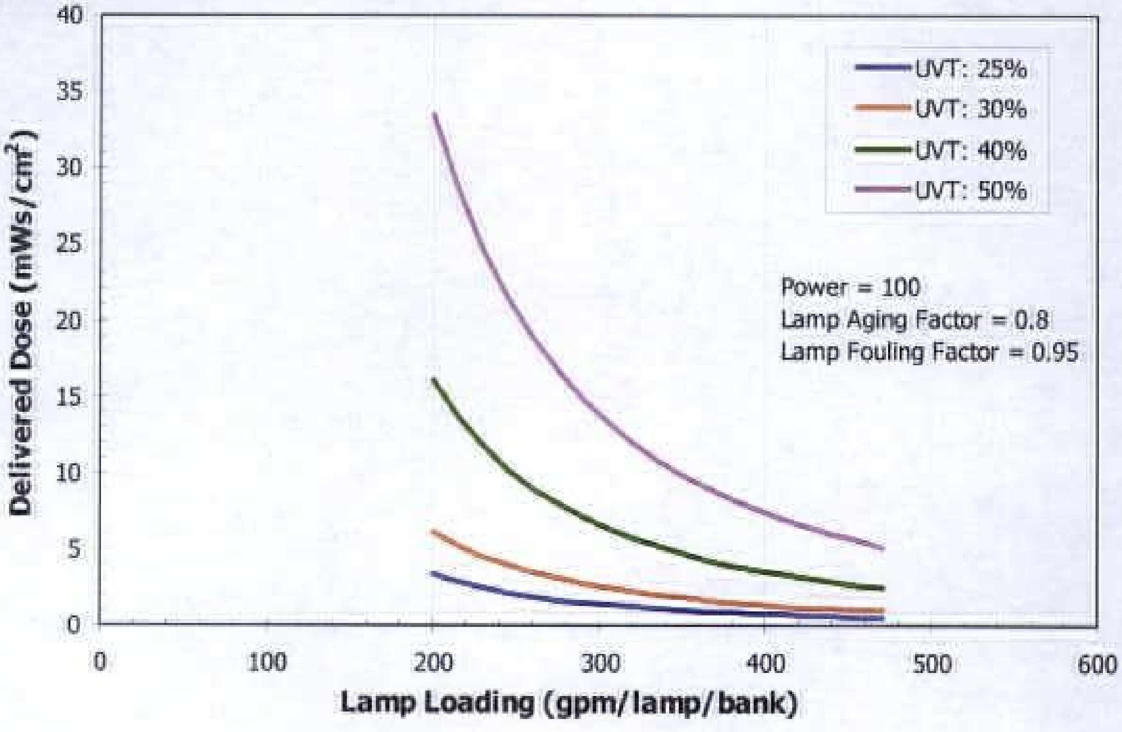
Log(log reduction)
= -0.4624 – 1.2563 log(flow/lamp/bank) + 0.6019 log(power) + 1.5260 log(UVT); R^2 = 0.75

These models determine the approximate number of UV lamps required given target disinfection efficiency (or delivered dose), flow rate, power setting, and water quality parameter (UVT), provided sufficient ranges of data were collected. The lamp aging factor (usually 0.8) and fouling factor (usually 0.95 with chemical/mechanical wiper) were not accounted for during the modeling process, but will need to be considered for system design.

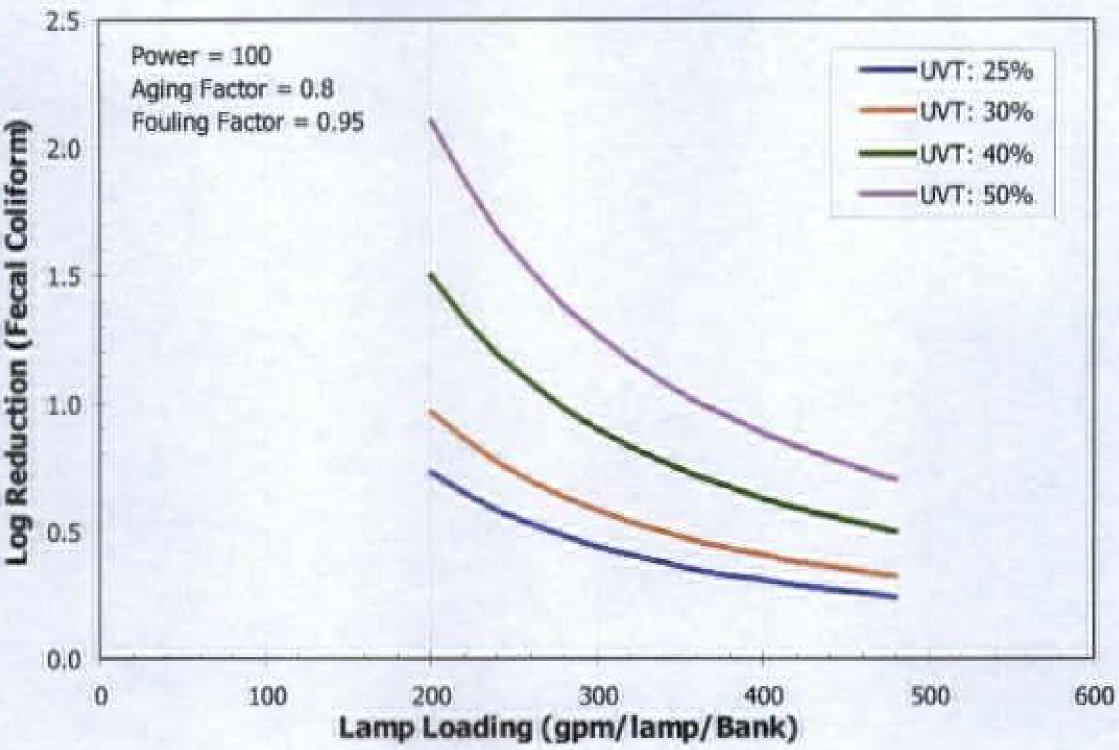
Figure 4-6 shows the delivered dose (**Figure 4-6a**) and log reduction (**Figure 4-6b**) as a function of lamp loading for given UVT values and 100% ballast power setting. The effect of fouling and lamp aging were accounted for by applying a fouling factor (0.95) and a lamp aging factor (0.8) to the modeled delivered dose or log reduction.

Figure 4-6
Multivariable Regression Models for Trojan Pilot Unit

(a) Delivered Dose vs. Lamp Loading



(b) Fecal Coliform Log Reduction vs. Lamp Loading



Using the delivered dose MLR model (**Figure 4-6a**), one can make a quick estimate of number of UV lamps required to achieve a target disinfection efficiency for a given water quality and flow rate. The general procedure could be: perform the collimated beam test on the water sample, from which the delivered dose to achieve the target disinfection efficiency can be determined; then input the dose, UVT, and power, the lamp loading can be determined; finally, the number of lamps can be calculated for a given flow rate.

With the log(log reduction) model (**Figure 4-6b**), the performance of a given UV system (with known number of lamps) can be predicted throughout a typical CSO event. In this case, the lamp loading is known at different stage of overflow, UVT can be monitored (which generates a pollutant graph), then the disinfection efficiency at each stage of the overflow event can be predicted, hence an event mean disinfection efficiency can be estimated.

Figure 4-7 shows the log reduction vs. flow rate for an 8000 UV lamp system based on the log(log reduction) MLR model. It should be noted that the model prediction may exhibit a higher degree of deviation when the lamp loading is out of the pilot testing range (200-465 gpm/lamp).

Figure 4-8 shows the comparison of model predicted log reduction to actual pilot testing log reduction (without consideration of lamp aging and fouling effect). The model performs very well for log reduction less than 2.5, which is understandable as the majority of the model input log reduction data is less than 2.5. The model slightly under (conservatively) predicts the disinfection efficiency.

Figure 4-7
Log Reduction vs. Flow Rate with 8000 UV Lamps

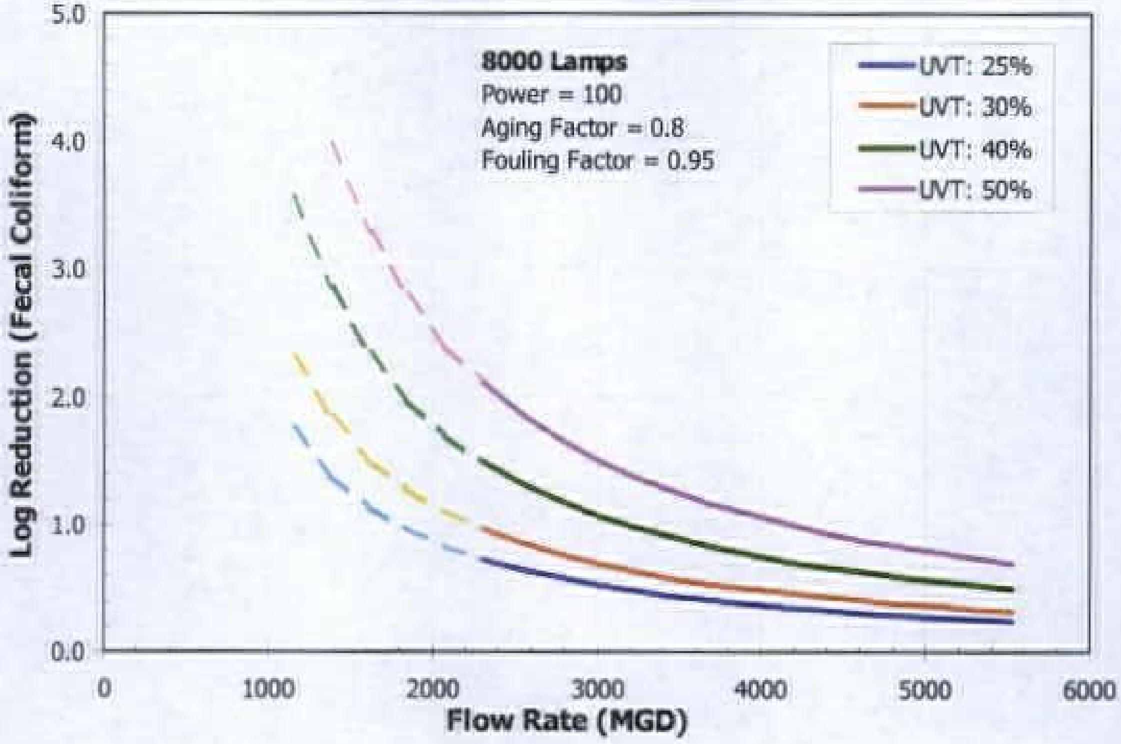
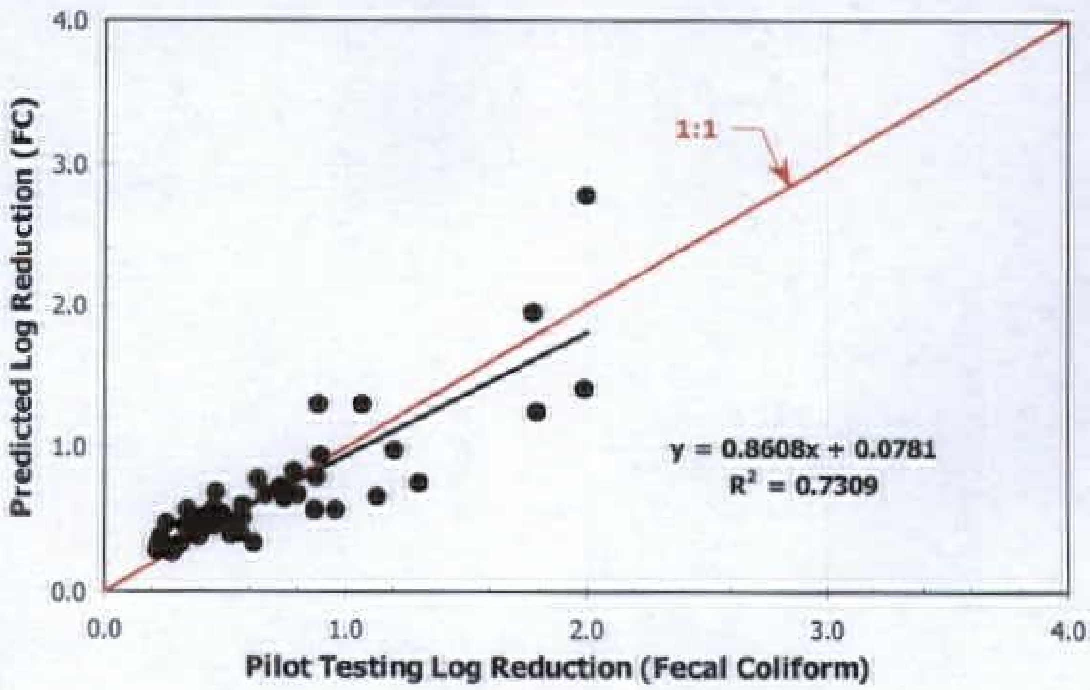


Figure 4-8
Comparison of Trojan Model Prediction and UV Pilot Testing Data



4.1.5.3.2 WEDECO Pilot Unit

There were not enough collimated beam test data available to develop the delivered dose model for the WEDECO unit. Majority of the tests were conducted with only one bank in operation and at 50% power setting, therefore only single bank pilot performance testing data were used for the multivariable regression analysis.

The log reduction data from the pilot testing ranged widely from 0.42 to 3.75 and fell along the collimated beam test dose-response curves. As indicated on **Figure 4-4(c)**, log regression would better describe the relationship between the delivered dose and log reduction for the WEDECO unit than linear regression, due to the fact that a majority of the inactivation data fell past the linear region of the dose response curve. Therefore, log reduction was chosen as the dependent variable for the WEDECO model.

The MLR models include Log transformed values for lamp loading, relative lamp output, TSS, and UVT as independent variables. Lamp loading is calculated by dividing the flow rate by number of lamps per bank (12), which varied from 8.3 to 34.3 gpm/lamp. Relative lamp output (RLO) is a term that describes the relative UV intensity resulting from ballast power settings utilized throughout the testing. The non-linear relationship between RLO and ballast power was measured on site with a constant UVT using measurements from the intensity sensor at ballast powers ranging from 50 to 100 percent. WEDECO's full-scale sizing approach incorporates the RLO term in the performance model in order to incorporate factors considered in full-scale system design (accounting for fouling and lamp aging). UVT varied from 20 to 56 percent.

The initial model analysis included log transformed values for lamp loading, relative lamp output, TSS, and UVT as independent variables. However, the model resulted with log(TSS) term being statistically insignificant. Therefore there was no additional impact of TSS on the disinfection performance of the WEDECO system over and above its impact on UVT. A second fecal coliform model was developed excluding the log(TSS) variable:

FC Log Reduction
$= -12.619 - 1.162 \log(LL) + 4.119 \log(RLO) + 5.815 \log(UVT);\ R^2 = 0.85$

Figure 4-9 presents the log reduction vs. lamp loading for different UVT values at 100% power. An example design factor of 0.76 (Lamp aging factor [0.8] x fouling factor [0.95]) was applied to the RLO term. It should be noted that due to the limited lamp loading range from the pilot tests (8-35 gpm/lamp, limited by the flow capacity of the pilot unit), simply extrapolating the model to high lamp loading values may introduce significant errors.

Figure 4-10 shows the comparison of model predicted FC log reduction to actual pilot testing FC log reduction (without consideration of lamp aging and fouling effect). The model performs very well for prediction of fecal coliform disinfection efficiency in the UV reactor as demonstrated by the R^2 value of 0.85.

Figure 4-9
Fecal Coliform Multivariable Regression Model for WEDECO Pilot Unit

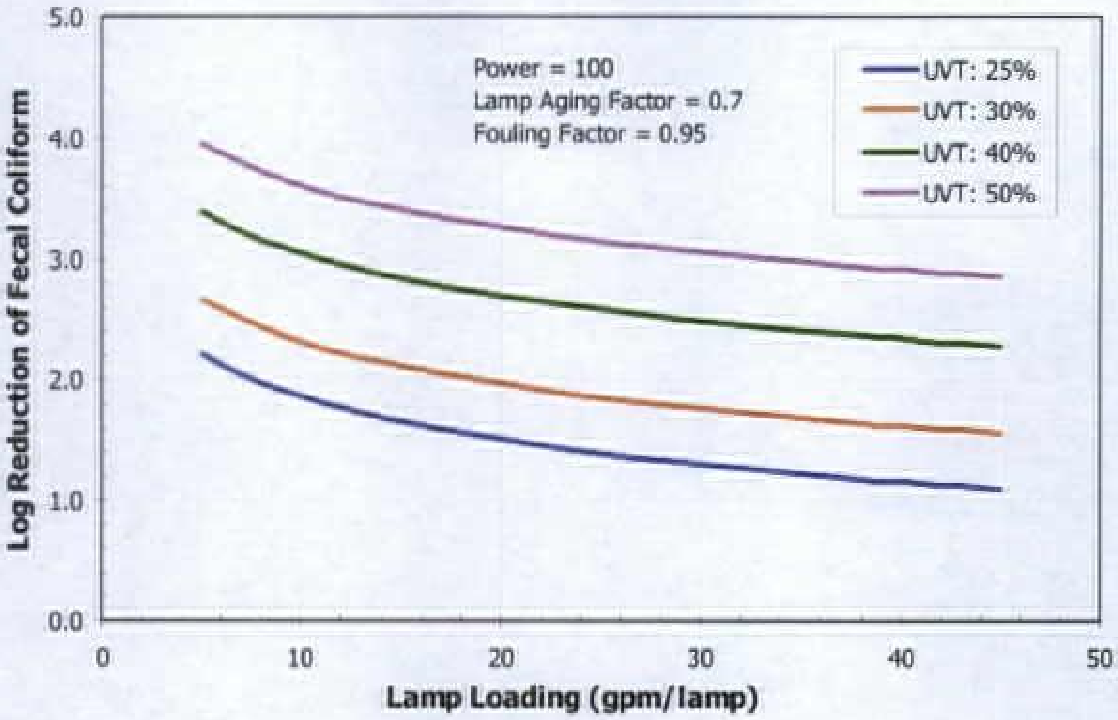
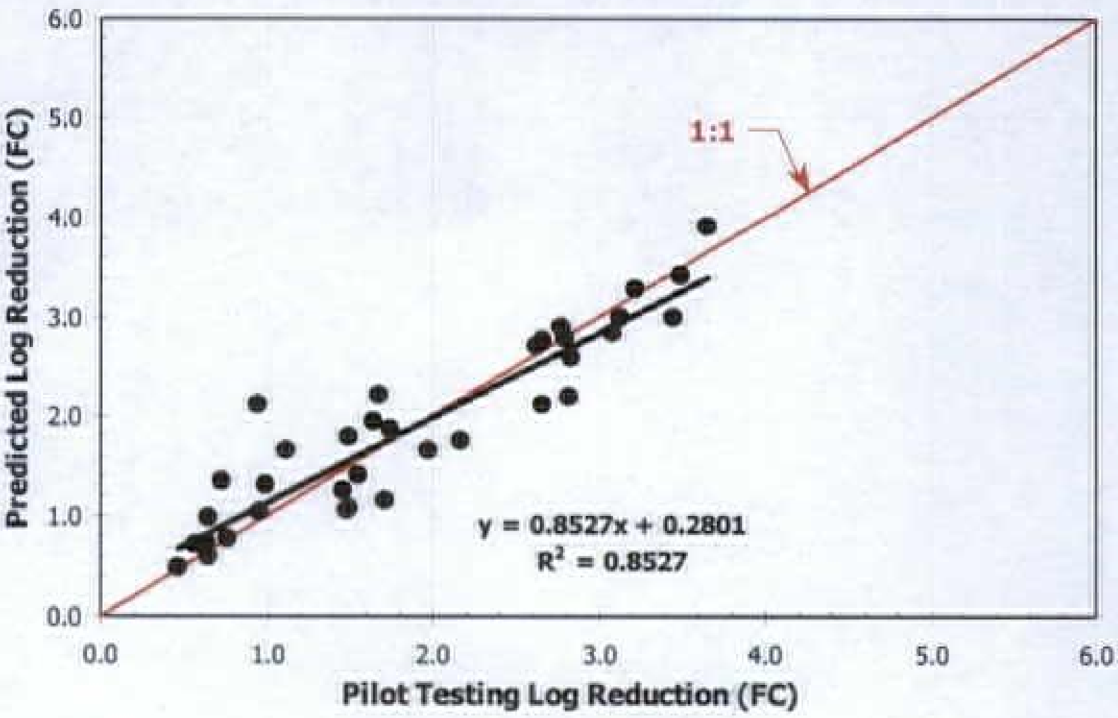


Figure 4-10
Comparison of WEDECO Model Prediction and UV Pilot Testing Data



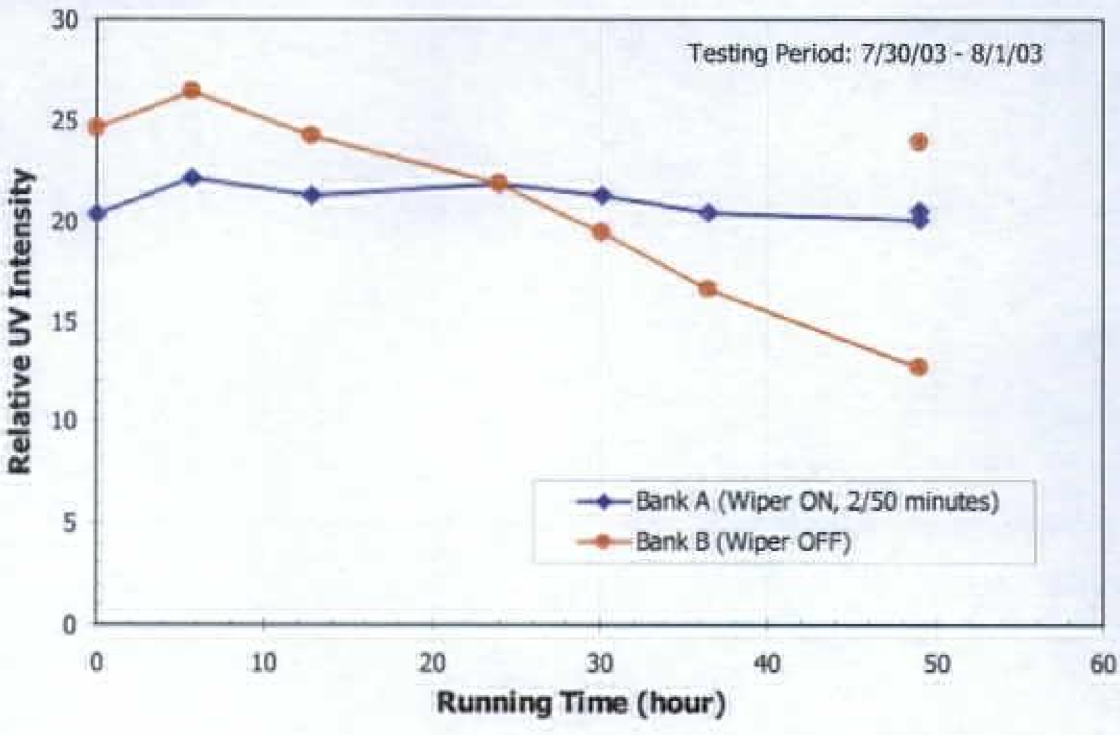
4.1.5.4 *Fouling / Wiper Efficiency Tests*

The WEDECO wiper efficiency was evaluated by comparing the in-channel UV intensity sensor readings from the two banks, one with automatic wiper in operation (2 wipes per 50 minutes), the other left dormant. As shown on **Figure 4-11**, UVT were relatively constant throughout the 2-day testing event, TSS was high (73 mg/L) at the beginning of the test, then stayed around 16 mg/L after 24 hours. The fouling causing constituents in the CSOs were at very low concentrations. Normally, fouling could be a problem when total iron > 0.3 mg/L, total manganese > 0.05 mg/L, and total hardness > 400 mg/L. The figure shows that the automatic wiper was effective in preventing quartz sleeves fouling. After the wiper was activated on Bank B, the UV intensity recovered to the value at the beginning of the test, which suggested that the wiper was able to effectively remove the deposits formed on the quartz sleeves. Visual observations confirmed that operating the wiper after each testing event could keep the quartz sleeves in a clean condition until the next wet weather event. Based on this, it is recommend that for potential full-scale system the wiper system be operated continuously for a few times at the beginning and end of each overflow event to effectively maintain the quartz sleeves clean.

The wiper efficiency for Trojan unit was evaluated by comparing the transparency of the quartz sleeves before and after 7-month testing period. **Figure 4-12** shows that the chemical/mechanical wiper system had been very effective to maintain the quartz sleeves clean. Similarly, the wiper system should be operated continuously for several times at the beginning and end of each overflow event.

Figure 4-11
Fouling/Wiper Efficiency Test Results for WEDECO Pilot Unit

(a) UV Intensity vs. Time



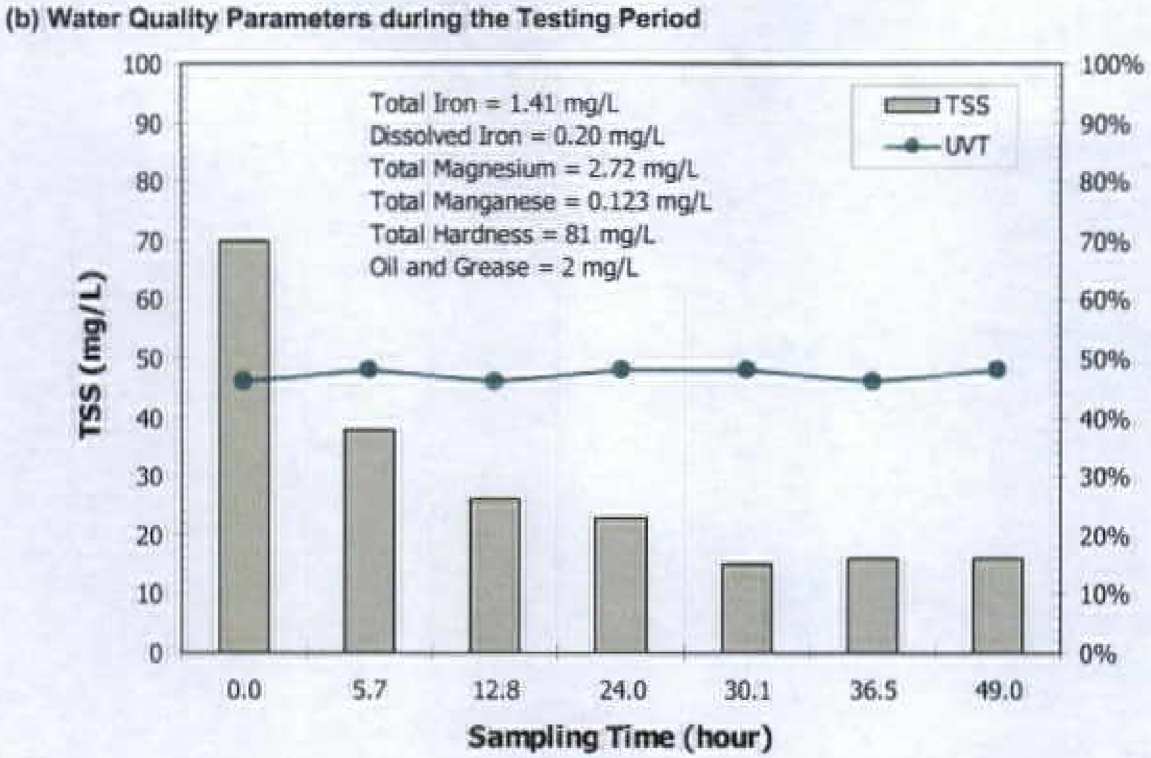
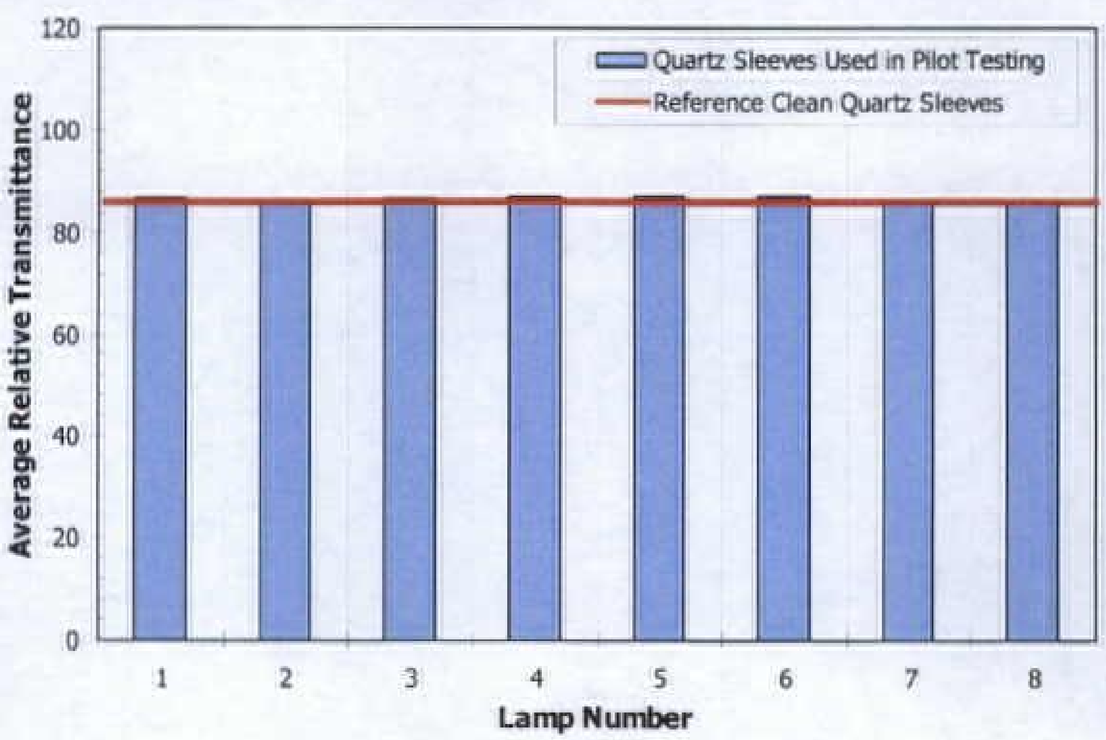


Figure 4-12
Effectiveness of the Trojan Chemical/Mechanical Wiper System



4.1.6 Summary

The 12-month UV disinfection pilot study demonstrated that UV appears to be a feasible technology for disinfection of Shockoe CSOs with at least 80% inactivation efficiency. The UV pilot system performance is dependent upon a number of variables including lamp loading (flow per lamp), relative lamp power output, and UVT. Multivariable linear regression models were developed to predict the delivered UV dose and/or log reduction in the reactor. The models will be used as input to the water quality model to determine the approximate number of UV lamps required given target disinfection efficiency (or delivered dose), flow rate, power setting, and water quality (UVT). Based on the number of UV lamps, the total power requirements for the UV system can be estimated. The power requirement, power up feasibility, power supply/generating infrastructure for the UV facility, as well as the associated cost, will be evaluated in the Phase III Program Project Plan. The automatic wiping systems from both UV units appeared to be effective in controlling fouling of the quartz sleeves.

4.2 CHLORINE DISINFECTION STUDY

4.2.1 Bench-Scale Chlorination Testing Protocol

4.2.1.1 *Overview*

The bench-scale chlorination study protocol was developed based on the *EPA Testing Protocol for Bench-Scale High-Rate Disinfection of CSOs (1975).* As described in Section 3, the disinfection efficiency of chlorine is impacted by a number of factors, including speciation and concentration of chlorine compound, contact time, initial mixing, reactor design, temperature and wastewater characteristics. In this study, the testing protocol was designed to mainly evaluate the effect of chlorine concentration and contact time for various wastewater qualities. The testing results will be used for development of a performance model that can be input into the combined sewer system model and James River water quality model to evaluate the feasibility of chlorine and identify the preliminary design criteria for Shockoe CSOs.

4.2.1.2 *Testing Wastewater*

The testing wastewater samples during the study were collected from Shockoe Retention Basin and Richmond WWTP primary sedimentation tank effluent channel. Preliminary testing showed that wastewater characteristics of the Shockoe Retention Basin CSO and the WWTP primary effluent was very similar and the majority of the water quality parameters of interest were quite comparable. Primary effluent has been used widely as a surrogate for CSO for disinfection study.

4.2.1.3 *Testing Procedures*

All glassware was cleaned in 10% nitric acid bath and chlorine bath, and autoclaved. The test was conducted on 1000 mL of wastewater sample in a chlorine-demand free glass vessel. The sample was homogenized with a rotary homogenizer for 1 minute to provide a uniform suspension prior to addition of chlorine. Chlorine stock solution was prepared by diluting Chlorox® into deionized water and standardized on the day of use by sodium thiosulfate titration in accordance with Standard Method 4500-Cl B.

For each test, appropriate volume of chlorine solution was applied to the wastewater sample to achieve target chlorine concentration. The chlorine solution was quickly mixed with the wastewater sample upon application for 15 seconds, then the sample was kept static throughout the rest of the contact time. At each contact time of 3, 6, 9, 12 and 30 minutes, 10 mL of sample was removed for free and combined chlorine residual analysis, and appropriate volume of sample (ranging from 10 to 20 mL depending on the anticipated bacteria concentration) was transferred to an autoclaved test tube for fecal coliform and *E. coli* analysis; the test tube contained appropriate amount of sodium thiosulfate solution to quench the residual chlorine in the sample.

For each wastewater sample, the following water quality parameters were analyzed in the lab of Froehling & Robertson, Inc. at Richmond: temperature, pH, TSS, ammonia nitrogen, TKN, nitrite, COD and BOD_5. Chlorine residuals were measured using DPD method with a portable colorimeter (LaMotte 1200-CL), and Fecal coliform and E. coli were measured at the WWTP lab in accordance with the Standard Methods described in **Section 4.1.4**.

4.2.2 Results and Discussions

Seventeen (17) chlorination tests were performed between January 2004 and March 2005. The testing water quality characteristics are summarized in **Table 4-3**. The water quality of the CSO sample had a greater variability than that of the primary effluent.

Table 4-3
Wastewater Characteristics During Chlorination Study

Parameter	Value
Ammonia Nitrogen	1.5-16.7 mg/L; Average 12 mg/L
Nitrite	< 0.088 mg/L
TKN	2.9-33.2 mg/L; Average: 21 mg/L
TSS	23-109 mg/L; Average 67 mg/L
COD	34-224 mg/L; Average 102 mg/L
BOD	16-135 mg/L; Average 105 mg/L
pH	6.3-7.1; Average 6.7
Temperature	10-20 °C; Average 16 °C
Fecal Coliform	420,000-4,460,000 cfu/100 mL; Average 1,460,000 cfu/100 mL
E. Coli	180,000-2,100,000 cfu/100mL; Average 640,000 cfu/100 mL

4.2.2.1 *Speciation of Chlorine Compounds*

As described in **Section 3**, at the presence of ammonia nitrogen, chlorine will react with ammonia nitrogen to form three types of chloramines, namely, monochloramine, dichloramine, and trichloramine. When the weight ratio of chlorine to ammonia is 5:1 or less, all of the free chlorine will be converted to monochloramine. In this study, the weight ratio of chlorine to ammonia ranged from 0.2 to 1.7, therefore all of the chlorine was essentially converted to monochloramine upon application. This kinetics of this reaction is very sensitive to pH and temperature, with the fastest rate at pH 7 to 8. As temperature drops the reaction slows appreciably (from less than a second at 25 °C to nearly 5 minutes at 0 °C). At the testing pH and temperature range during this study, the monochloramine should have been formed within one minute upon addition of chlorine.

4.2.2.2 *Chlorine Decay*

The chlorine decay curves during the study period are presented in **Figure 4-13**. As the figure shows, the chlorine concentration in the batch reactor decreased rapidly in the beginning of the reaction, and very moderately after satisfaction of the initial chlorine demand. The chlorine decay can be approximately described by two first-order equations: one for contact time less than 3 minutes and the second for contact time greater than 3 minutes. Both first-order equations have the following form:

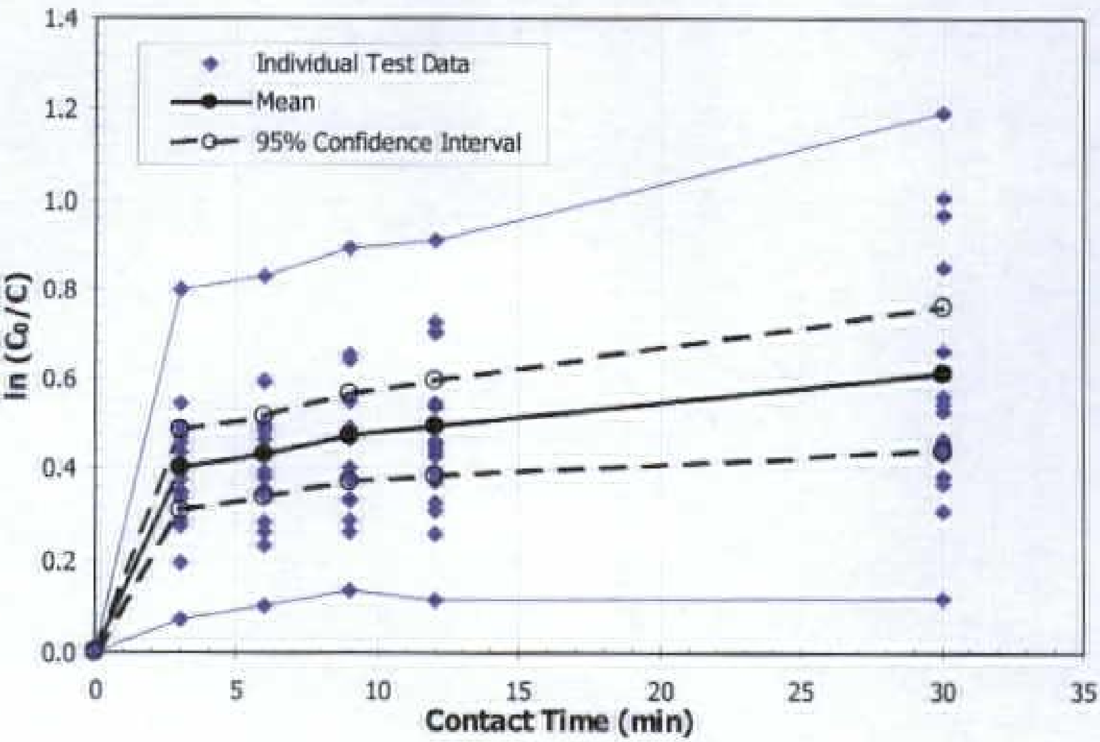
$$C = C_0 e^{-kt}$$

The two first-order reactions can be integrated into one equation such as the one shown below (developed by Haas and Karra in 1984):

$$C = C_0[xe^{-k_1 t} + (1-x)e^{-k_2 t}]$$

where, C is total chlorine residual concentration (mg/L), C_0 is chlorine dose (mg/L), x is an empirical constant, t is contact time (min), k_1 and k_2 are rate constants (min^{-1}).

Figure 4-13
Chlorine Decay Curves



It should be noted that the initial chlorine demand could have been satisfied earlier than 3 minutes; in another word, the beginning of the second stage chlorine decay (flatter part of the curve) could occur at contact time less than 3 minutes. To develop an equation describing the initial chlorine decay kinetics would require chlorine residual measurements for contact time less than 3 minutes.

Figure 4-13 shows that the chlorine decay kinetics varied very widely from test to test, which could be attributable to the variability of water qualities. Although models described above can well represent the chlorine decay kinetics for each specific test, it would be of little practicability to try to develop one single model to predict chlorine residual concentrations during the CSO disinfection process.

4.2.2.3 *Disinfection Kinetic Model*

A number of mathematical models have been developed to describe the inactivating kinetics during batch chlorination. The simplest disinfection model is a combined one proposed by Chick and Watson. In the Chick-Watson model (shown below), the rate of inactivation of a microorganism is dependent upon the concentration of the disinfectant and contact time.

Chick-Watson Model: $\log\frac{N}{N_0} = -kC^n t$, where k and n are empirical constants.

In 1972, Hom proposed a model to account for deviations from the Chick-Watson model in practice by applying empirical constants on both C and t terms. Later on, some other researchers made modifications to the Hom model by substituting the chlorine concentration C with the first-order chlorine decay equation. The coefficients m and n can be determined by multivariable linear regression. Note that log reduction (LR) is defined as log N_0/N.

Hom Model: $\log\frac{N}{N_0} = -kC^n t^m$

Multivariable Linear Regression: $\log\left(\log\frac{N_0}{N}\right) = \log k + n\log C + m\log t$

In 1970s, Selleck and Collins developed a general kinetic expression for the effect of combined chlorine residual on both total and fecal coliform. In this model, $N/N_0 = 1$ when $C\,t <= b$. The coefficients b and n can be determined by plotting the log N/N_0 vs log Ct.

Selleck-Collins Model: $\frac{N}{N_0} = \left(\frac{b}{Ct}\right)^n$, where b and n are empirical constants.

In this study, both Hom model and Selleck-Collins model were used to describe the bench-scale testing data. Again, only the fecal coliform models are presented here:

$$\text{Hom Model: Log Reduction (FC)} = \log\frac{N_0}{N} = 0.02722C^{1.5210}t^{1.1788},\ R^2 = 0.79$$

$$\text{Selleck-Collins Model: } \frac{N}{N_0} = \left(\frac{5.6828}{Ct}\right)^{3.1211},\ \text{or LR} = 3.1211\ \log(Ct) - 2.3551,\ R^2 = 0.83$$

The Selleck-Collins model was selected in this study based on two major considerations: 1) the Selleck-Collins model has a slightly better correlation coefficient; 2) the Hom model tends to significantly over-predict as Ct increases to above 90 mg/L-min. **Figure 4-14** shows the testing data and Selleck-Collins Model. The comparison of the model predicted log reduction and the observed log reduction is presented in **Figure 4-15**.

Figure 4-14
Selleck-Collins Model

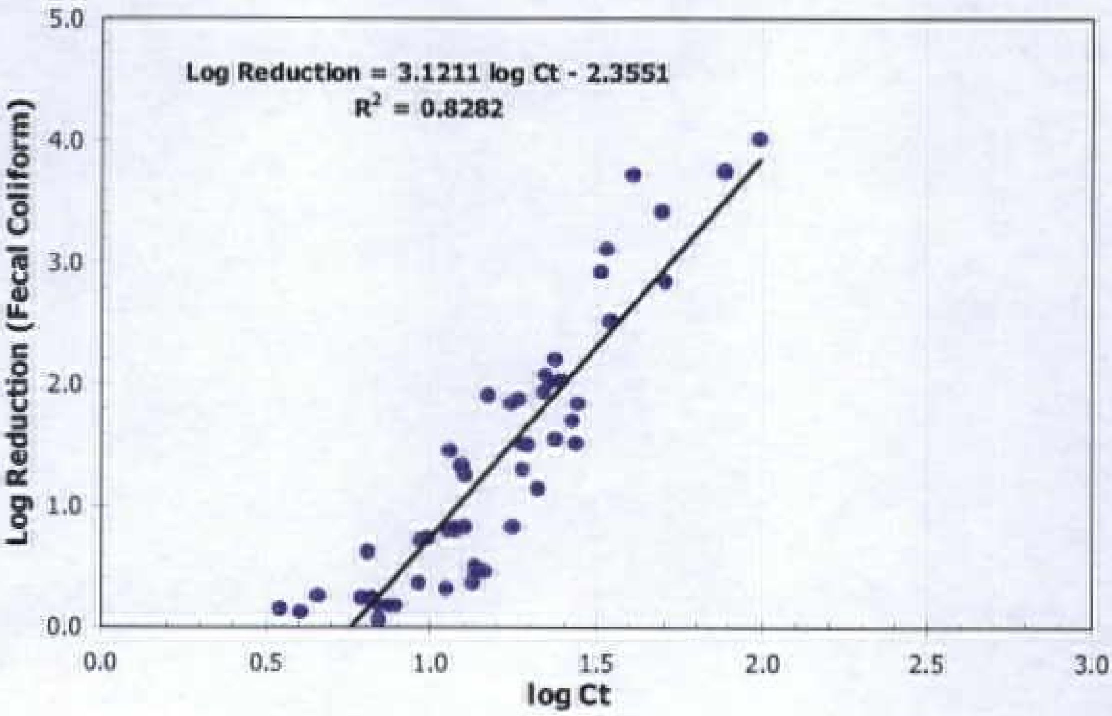
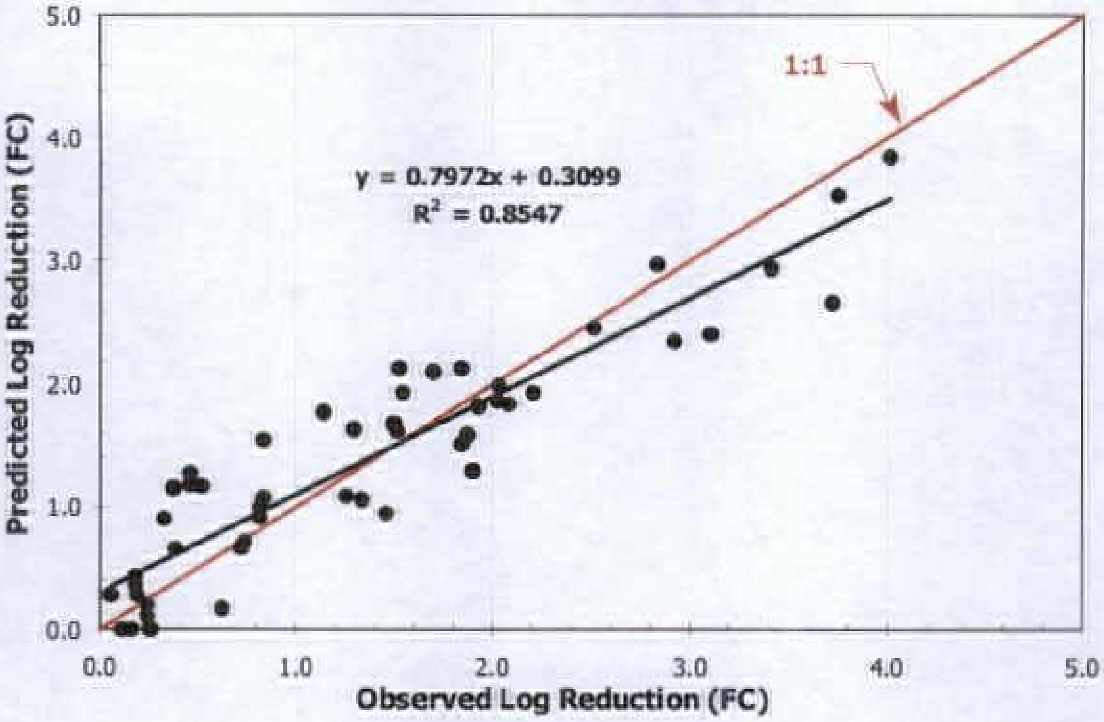


Figure 4-15
Comparison of Model Prediction and Chlorination Testing Data



4.2.3 Summary

The bench-scale chlorination test demonstrated that for Shockoe CSO and primary effluent, up to 4-log reduction of fecal coliform could be achieved at chlorine doses less than 7 mg/L with contact times between 3 and 30 minutes. All free chlorine was converted to monochloramine upon application into the wastewater. The testing data can be well described by Selleck-Collins model. Based on this model, the CT value (defined as total chlorine residual concentration multiplied by contact time) to achieve 80% (0.7-log), 90% (1-log), 99% (2-log), 99.9% (3-log), and 99.99% (4-log) reduction is approximately 9.5, 12, 25, 52, and 109 min-mg/L, respectively. In **Section 5**, the Selleck-Collins model will be input into the combined sewer system model and James River water quality model to identify the chlorine dose required to achieve various water quality improvements in the James River.

City Of Richmond, Virginia
Department Of Public Utilities

CSO Disinfection Study

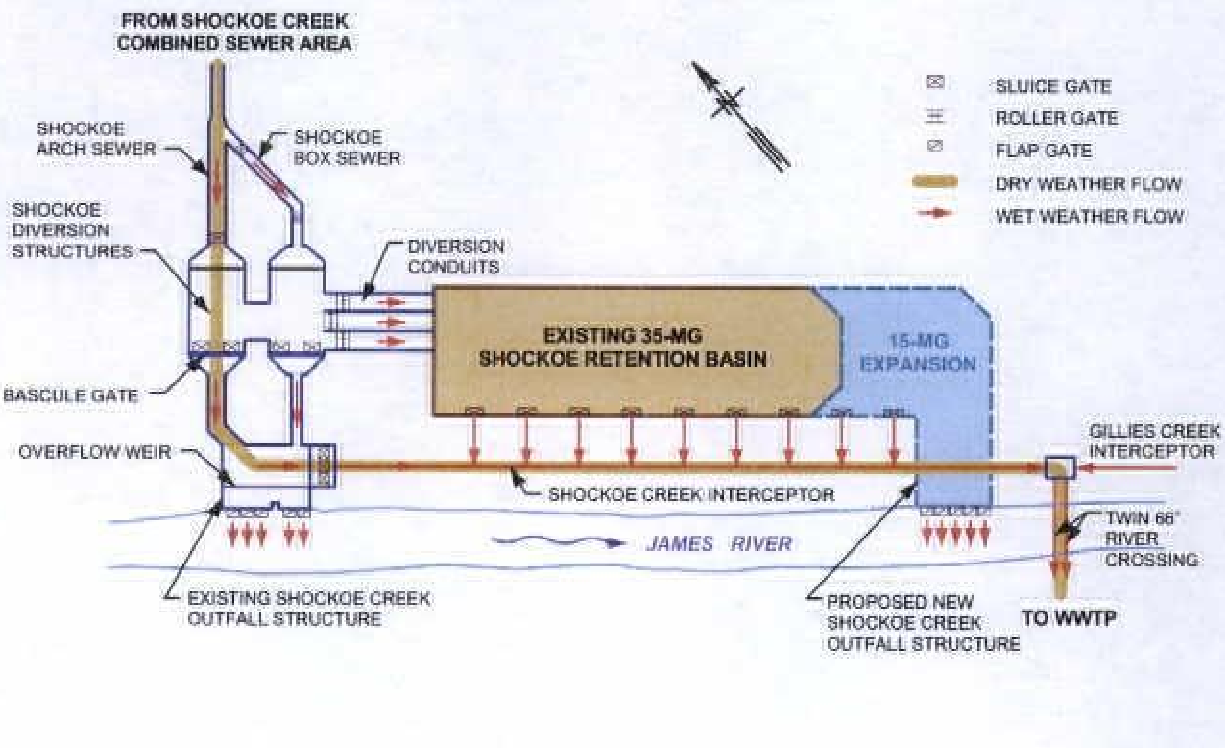
SECTION 5
FINDINGS AND CONCLUSIONS

Greeley and Hansen LLC
June 2005

5.1 INTRODUCTION

The UV multivariable linear regression model and the chlorine bacteria reduction model are being used to determine the bacteriological water quality that could be achieved for a given Shockoe Disinfection Facility. The bacteria reduction models are applied to the dynamic flows from the combined sewer system hydraulic model, which will more accurately account for the changes in disinfection performance as a function of flow. This section provides the preliminary water quality model results for a range of UV and chlorine disinfection facilities for the Shockoe outfall. The expansion of the Shockoe Retention Basin is shown schematically on **Figure 5-1**. The existing outfall will be relocated to the east end of the expanded basin, and the proposed disinfection facility will be constructed in the 15-MG new chamber.

Figure 5-1
Schematic of Shockoe Expansion



5.2 BACKGROUND

5.2.1 Combined Sewer System Hydraulic Model

The five-year period starting January 1974 through December 1978 (selected from the entire period of hydrological record from the City of Richmond) conservatively represents the average rainfall pattern for the City of Richmond. This entire five-years of rainfall record is applied to the combined sewer system model in a continuous simulation to determine the volume and flow rate of combined sewer overflow that would be discharged to the James River in the average year. This EPA SWMM hydraulic model was calibrated during the development of re-evaluation report of the City's CSO LTCP. Flow rates every 5 minutes for the continuous five-year period are applied to the bacteria reduction models, which will determine the amount of bacteriological load that will be discharged into the receiving water model.

5.2.2 James River Water Quality Model

The receiving water model used to determine the water quality in the James River is the one-dimensional PULSEQUAL model, which can be applied to free flowing or tidal rivers. The PULSEQUAL model was constructed for the tidal stretch of the James River directly impacted by CSO discharges. The model stretches from the head of tide near the I-95 Bridge (Shockoe Outfall) to a point 20 miles downstream near Curles Neck Plantation. The PULSEQUAL model was also calibrated during the re-evaluation of the City's CSO LTCP using fecal coliform data from the City's Bacteriological Monitoring Program and Storet data. The 5-minute bacteriological flow and load data from the combined sewer system hydraulic model and the bacteria reduction models are compiled into a 4-hour increment, which is applied to the PULSEQUAL model for the 5-year continuous simulation of James River water quality.

5.2.3 *E. coli* Translator

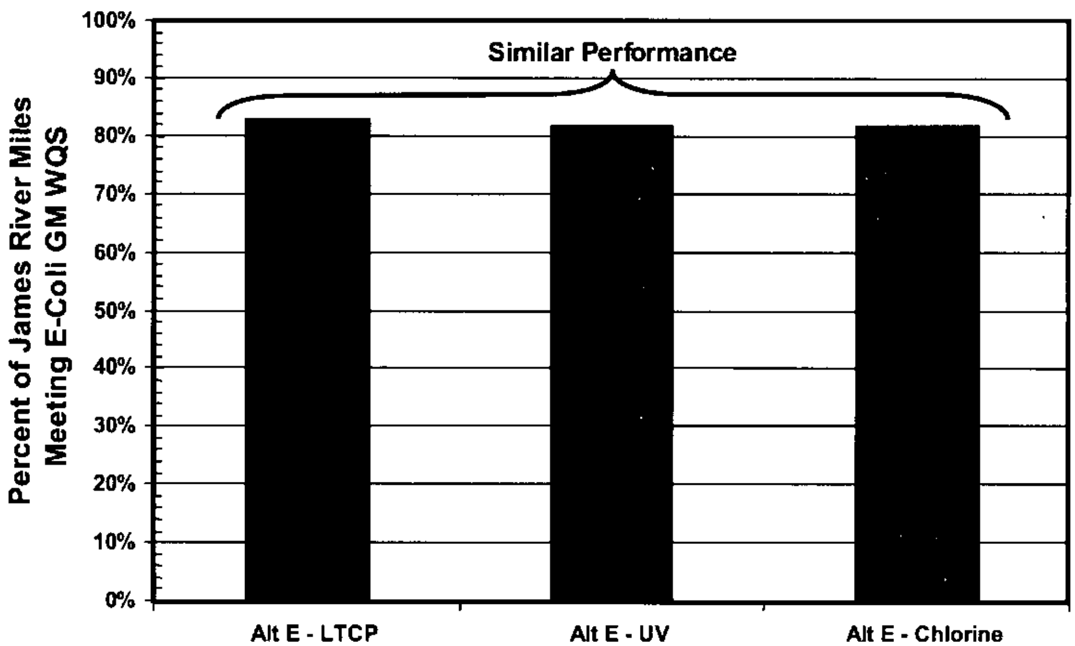
A fecal coliform to *E. coli* translator was developed based on the City's extensive Bacteriological Monitoring Program, which collected enough data of both indicator organisms to create a translator specific to James River at Richmond. Since there is substantially more fecal coliform data to calibrate the James River Water Quality Model, the bacteriological load and the bacteria reduction models are based on fecal coliform. The output from the James River Water Quality Model on a 4-hour basis is translated to *E. coli* and processed to show the water quality results for each model run in terms of monthly geometric mean and upper percentile value (single sample maximum).

5.3 FINDINGS

5.3.1 Shockoe Disinfection Water Quality Performance

Figure 5-2 shows that the UV and chlorine disinfection at Shockoe will provide about the same level of treatment as predicted in the January 2002 CSO LTCP Re-evaluation Report (Alternative E).

Figure 5-2
Comparison of Potential Shockoe Disinfection Facility Performance To Alternative E Shown In CSO LTCP



The water quality performance for a range of UV and chlorine disinfection systems at the Shockoe outfall is shown on **Figure 5-3** and **Figure 5-4**, respectively. Both figures show diminishing water quality returns for larger disinfection facilities. The water quality model results suggest that construction of the South Side Disinfection Facility will be the next large increment in water quality benefit. It also appears that at even a minimum level of disinfection at Shockoe will provide almost the same benefit as complete city-wide separation, which may be more than 5 times as expensive when compared to Alternative E. The full water quality modeling results for each model run is provided in **Appendix A** of this report.

Figure 5-3
Performance With UV Disinfection Facilities

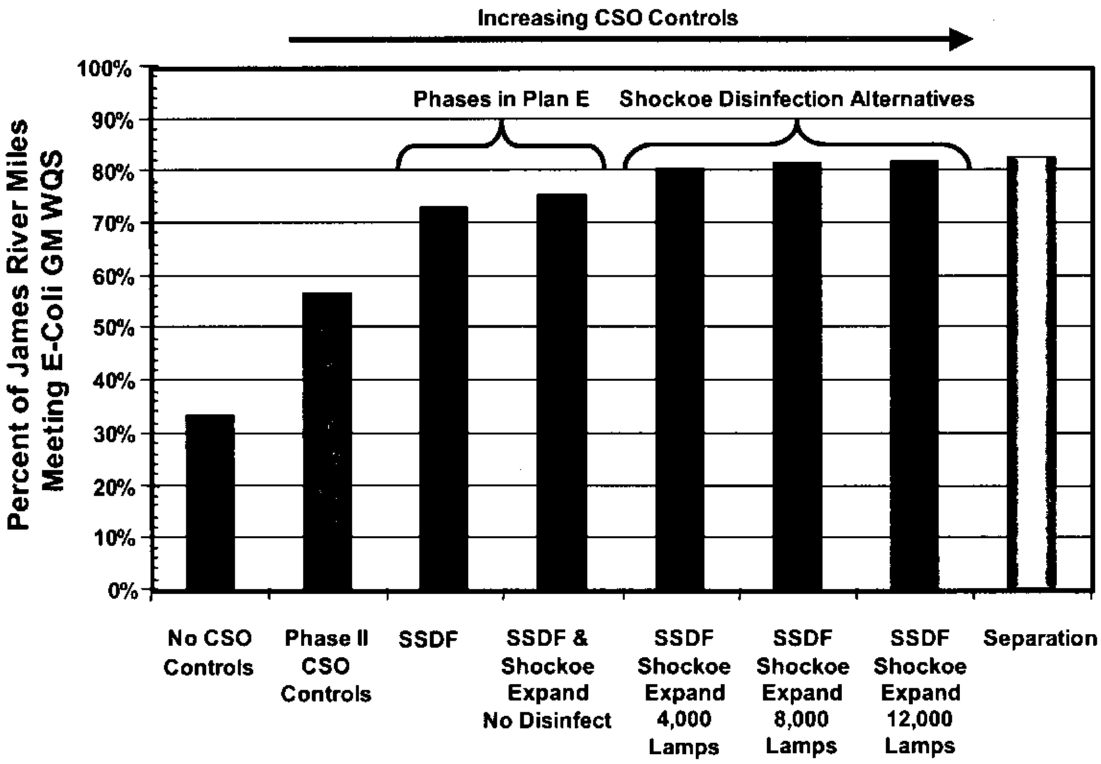
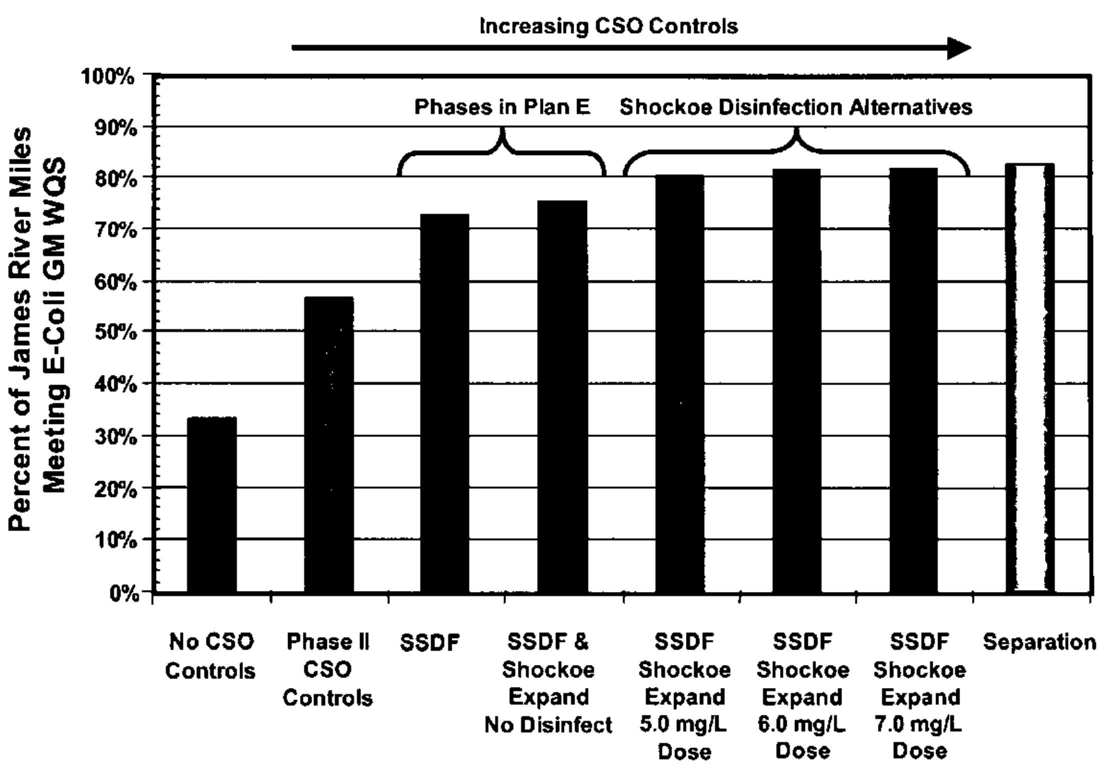


Figure 5-4
Performance With Chlorine Disinfection Facilities



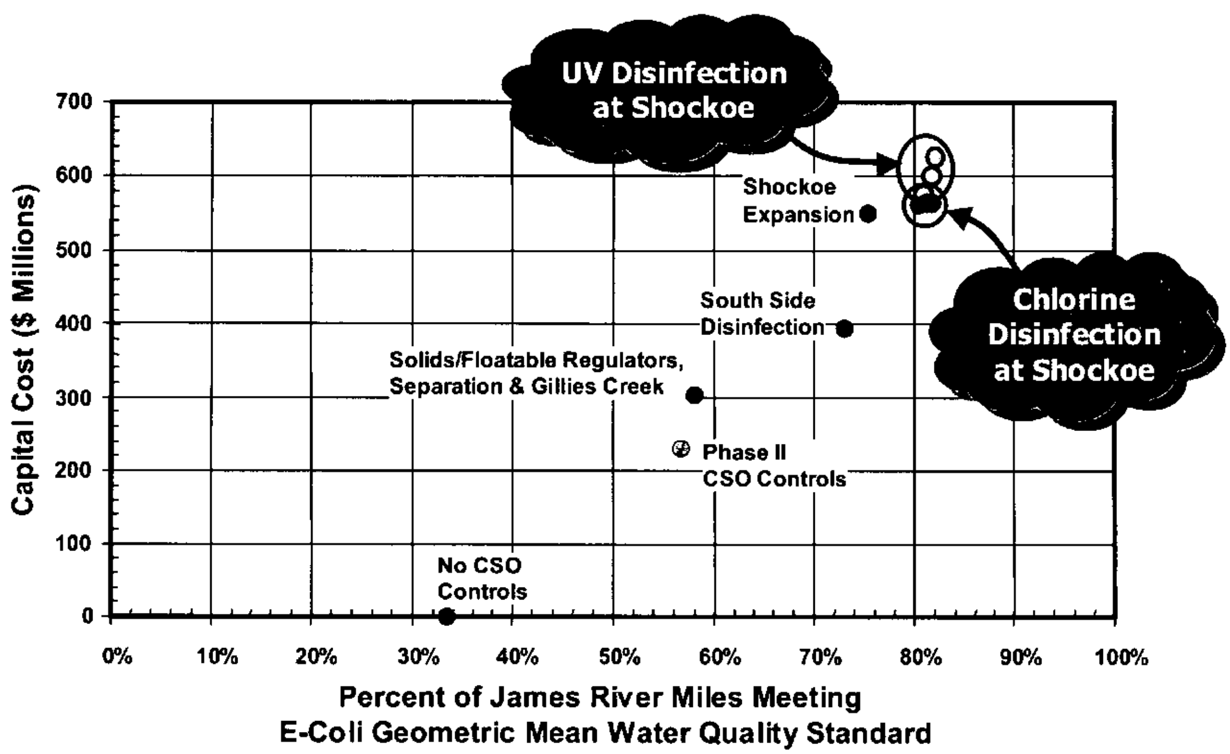
5.3.2 Preliminary Benefit-Cost Analysis

The preliminary benefit-cost analysis, shown in **Figure 5-5**, suggests that disinfection with chlorine is more cost effective than UV disinfection at Shockoe. However, UV disinfection has a number of advantages, including:

- Disinfection is not depended on the amount of chemical stored onsite. Provides continuous disinfection during large volume storms events.
- No increase in truck traffic associated with chemical deliveries.
- No dechlorination chemical required.

There are other potential alternate disinfection arrangements that may improve the cost effectiveness of a UV disinfection system at Shockoe. These may include the disinfection at lower flow rates with higher disinfection efficiencies. These alternate arrangements will be evaluated as part of the expansion of the retention basin. The full benefit-cost evaluation will be included in the Program Project Plan.

Figure 5-5
Benefit To Cost Analysis

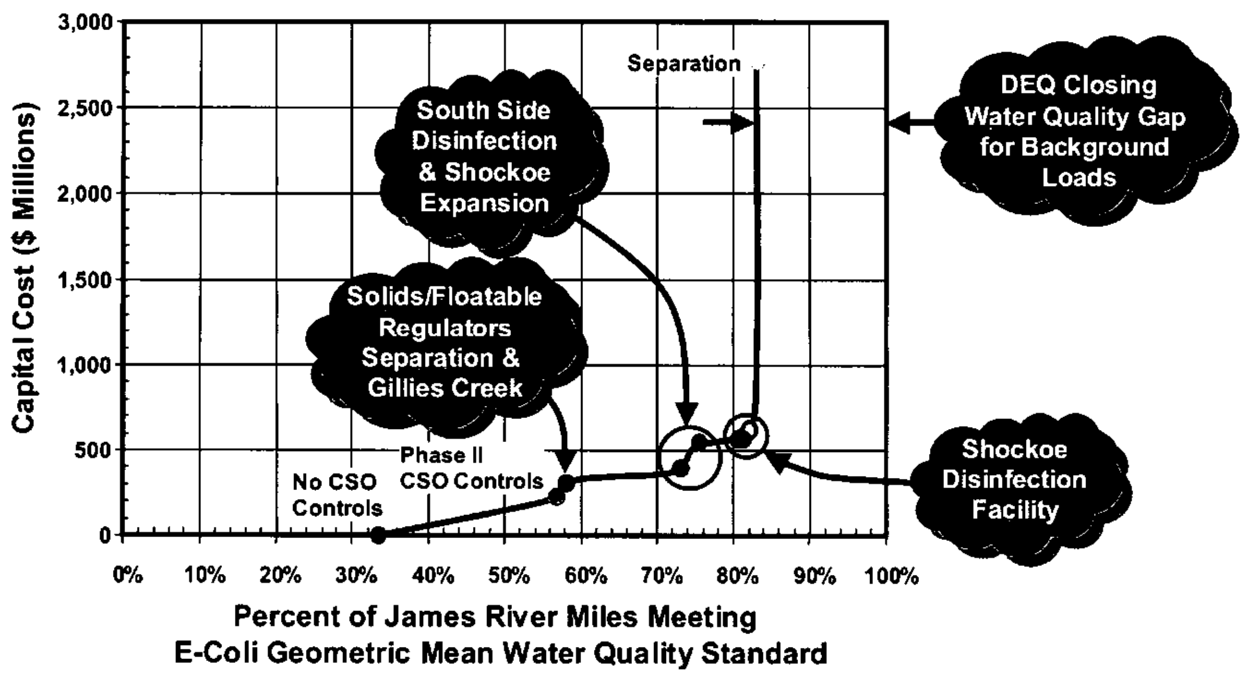


5.3.3 Model Results for Water Quality Standards Coordination Process

The DEQ will be conducting a water quality standards coordination process for bacteria. The following model runs could be used in this process.

- **Figure 5-6** shows the water quality gap for background loads that DEQ is closing as part of the water quality standards coordination process.
- **Figure 5-7** and **Figure 5-8** shows the model results for Reach 13 (about 6 miles down stream of the City) in August. Reach 13 is an example of river mile that exceeds the water quality standard, but is very close to EPA's acceptable fresh water risk level of 10 illnesses per 1,000 as published in their May 2002 and November 2003 draft Implementation Guidance for Ambient Water Quality Criteria for Bacteria.
- As shown in **Appendix A** for the Phase II CSO Controls, currently water quality standards are met during the months of January, February, March and April. Further improvements under Phase 3 will add compliance for the months of September, October and November[1] as shown in the model result for expansion of the Shockoe Retention Basin with no disinfection. Coincidentally, these are the colder months of the year when the James River is used less. This water quality performance and recreational use patterns suggest the use of seasonal disinfection will have the potential to further reduce costs.

Figure 5-6
Water Quality Standards Coordination



[1] The water quality in the month of December is close to compliance with E. coli monthly geometric mean water quality standard. The water quality standard is met at the City border for month of December. However, the downstream background load appears to impact the water quality in the James River.

Figure 5-7
Shockoe UV Disinfection Facility Performance
James River Water Quality At Reach 13 For August

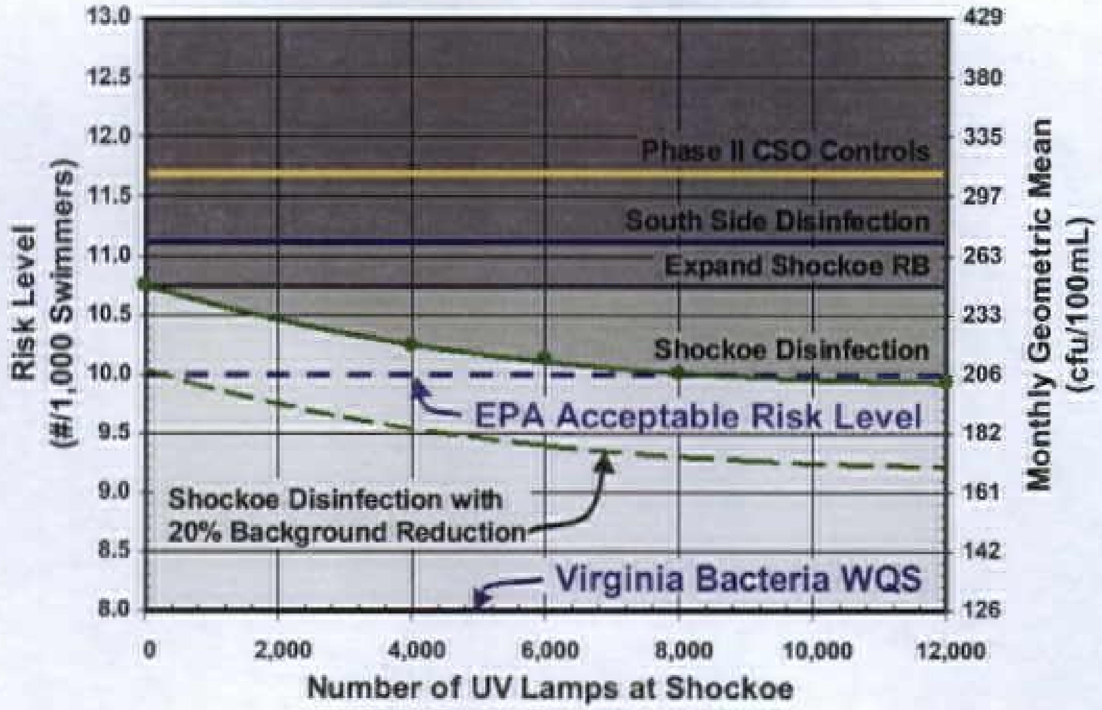
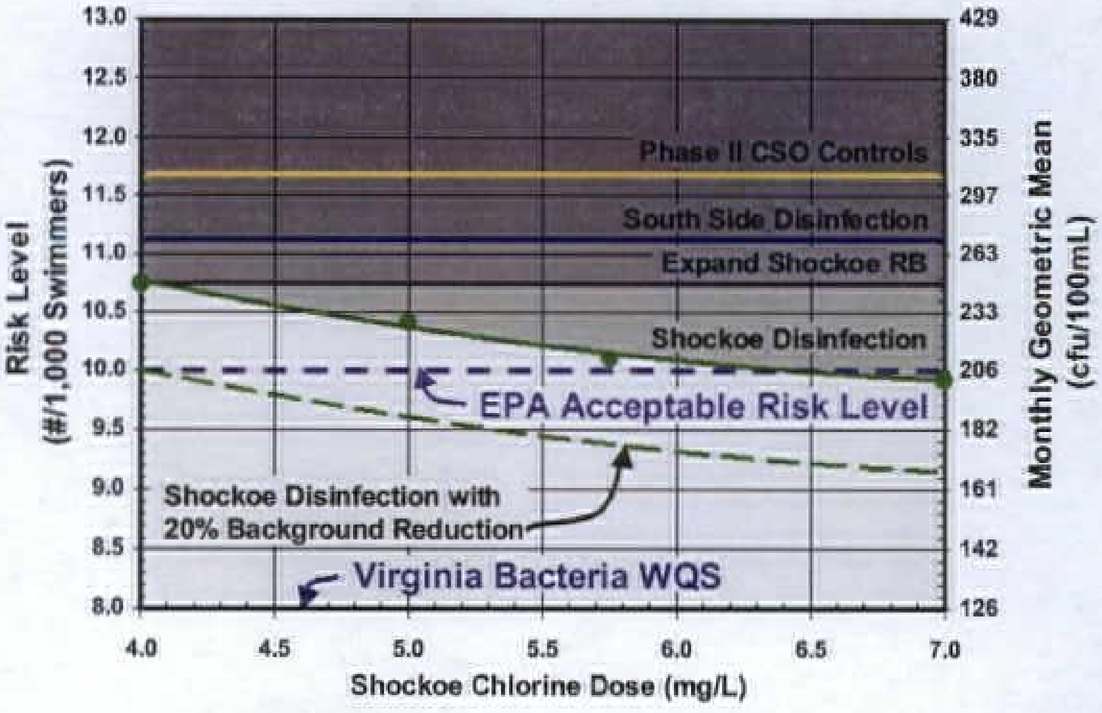


Figure 5-8
Shockoe Chlorine Disinfection Facility Performance
James River Water Quality At Reach 13 For August



5.4 CONCLUSIONS

The pilot studies described in this report document that reliable disinfection levels of 80% (bacteriological reduction at Shockoe) and higher can be achieved using UV or sodium hypochlorite (NaOCl) disinfection. Preliminary cost estimates suggest that the use of NaOCl is more economical. However, the complete life cycle cost analyses must also include evaluation of physical location of the proposed disinfection facility, tangible costs, intangible factors, O&M considerations and input from the City's staff. Alternatives for cost reductions with UV and with NaOCl include the potential disinfection of lower flow rates at higher levels of bacteriological reductions. These evaluations will be included in the development of the Program Project Plan.

5.5 NEXT STEPS – DEVELOPMENT OF THE PROGRAM PROJECT PLAN

Comparative evaluation of the alternative disinfection methods established as technical feasible in this study, in conjunction with expanding the Shockoe Retention Basin.

- Full benefit-cost evaluation based on benefits in terms of illness risk and annual costs, which reflect both capital and O&M requirements.
- Bacteriological model results could be used in the Water Quality Standards Coordination Process
- Finalize the conceptual design of the disinfection facilities

City of Richmond, Virginia
Department of Public Utilities
Phase III CSO Control Program

Funded by U.S. Army Corps of Engineers, Norfolk District
Under Contact No. DACW65-01-C-0052

CSO Disinfection Report

Appendix A
Water Quality Model Results
Translated to *E. coli*

FINAL REPORT

June 2005

Greeley and Hansen LLC
with LTI, Inc

City of Richmond, Virginia
Department of Public Utilities
Phase III CSO Control Program

Funded by U.S. Army Corps of Engineers, Norfolk District
Under Contact No. DACW65-01-C-0052

CSO Disinfection Report

Appendix A
Water Quality Model Results Translated to *E. coli*

Model Runs From 2002 CSO LTCP Re-evaluation Report

FINAL REPORT

June 2005

Greeley and Hansen LLC
with LTI, Inc

City of Richmond, Virginia
Department of Public Utilities
CSO Disinfection Report

James River Water Qualtiy Model Results

Background A2 - No CSO Controls

Greeley and Hansen LLC
June 2005

State WQS
CI 75%
State Std Dev

E-Coli - Percent of Time > 235 MPN/100ml

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Reach Average	Hrs/mo	days/yr
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
Avg 74-78	Jan	28	31	31	31	32	31	32	34	34	34	34	33	33	33	33	33	33	33	33	32	32.5	241.8	10.1
	Feb	26	28	29	28	28	28	30	32	32	31	31	30	30	29	28	27	27	26	26	26	28.6	192.4	8.0
	Mar	28	30	31	31	31	31	34	36	38	38	37	37	37	36	36	35	34	33	33	32	33.9	252.2	10.5
	April	32	33	33	33	33	34	34	35	35	34	32	31	31	30	30	30	29	28	28	27	31.7	228.1	9.5
	May	45	47	49	50	49	49	51	53	53	52	52	50	49	48	45	43	42	40	38	37	47.2	351.5	14.6
	June	38	40	42	42	42	42	45	46	47	48	49	49	48	47	44	44	43	42	41	40	44.0	316.6	13.2
	Jul	47	50	51	52	51	50	51	53	52	50	48	46	44	41	40	38	35	34	32	30	44.7	332.8	13.9
	Aug	55	58	61	60	61	61	63	65	66	65	63	62	59	56	52	49	47	46	45	42	56.8	422.6	17.6
	Sept	41	43	46	47	47	48	48	50	51	50	48	44	41	38	36	35	34	33	32	31	42.2	303.6	12.7
	Oct	39	39	40	40	38	38	39	41	41	40	39	37	36	35	34	32	29	27	26	25	35.8	266.1	11.1
	Nov	46	46	47	47	46	45	45	45	44	42	40	39	36	33	31	27	25	23	21	20	37.4	269.2	11.2
	Dec	39	41	42	43	45	46	48	50	50	51	50	51	51	51	50	49	49	47	46	45	47.2	351.0	14.6

147.0
40.3% Exceed
59.7% Meet

State WQS
CI 75%
Local Std Dev

E-Coli - Percent of Time >334 MPN/100ml

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
Avg 74-78	Jan	24	26	27	27	28	28	28	30	29	29	29	28	28	27	27	27	26	26	26	26	27.3	203.4	8.5
	Feb	22	24	24	24	25	25	26	27	27	26	25	25	24	24	23	22	21	21	20	19	23.6	158.9	6.6
	Mar	27	29	30	29	29	29	30	32	33	32	31	32	31	30	29	30	28	28	27	26	29.6	220.4	9.2
	April	26	27	27	28	28	28	28	28	28	27	27	27	26	26	26	24	24	23	23	22	26.2	188.5	7.9
	May	35	38	40	40	41	41	43	46	46	45	44	42	40	38	36	34	33	32	30	29	38.6	287.3	12.0
	June	33	35	38	39	38	39	41	43	43	43	43	41	39	38	37	37	36	35	34	33	38.3	276.0	11.5
	Jul	43	45	45	45	44	44	45	47	46	44	43	39	37	34	32	30	28	27	25	24	38.3	285.1	11.9
	Aug	51	54	56	57	57	57	58	59	59	58	55	52	49	43	43	42	39	37	36	35	49.7	369.6	15.4
	Sept	33	35	37	38	39	41	42	43	41	40	36	34	33	32	31	28	27	26	24	23	34.1	245.7	10.2
	Oct	32	34	34	34	34	34	35	37	36	34	33	32	29	28	26	25	24	22	22	21	30.3	225.7	9.4
	Nov	40	42	42	41	41	40	39	39	38	37	33	29	25	22	20	19	18	17	17	16	30.6	220.3	9.2
	Dec	34	37	38	40	39	40	41	44	44	44	45	45	45	45	44	42	41	38	36	34	40.8	303.7	12.7

124.4
34.1% Exceed
65.9% Meet

EPA
Moderate
Contract
CI 82%
State Std Dev

E-coli - Percent of Time > 298 MPN/100ml

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
Avg 74-78	Jan	25	27	28	28	28	29	29	31	31	31	30	30	30	29	29	30	29	29	29	28	28.8	214.2	8.9
	Feb	22	24	25	25	25	25	27	28	28	28	27	26	25	25	25	24	23	23	22	22	24.9	167.7	7.0
	Mar	27	29	30	29	30	30	32	34	35	34	33	34	33	33	32	32	31	31	30	30	31.5	234.3	9.8
	April	27	28	28	28	28	29	29	30	29	29	28	28	27	27	27	27	27	26	26	23	27.6	199.0	8.3
	May	38	42	44	43	43	44	46	48	48	47	46	45	44	41	39	37	34	34	32	31	41.2	306.9	12.8
	June	34	37	39	40	39	40	42	44	45	45	45	45	43	41	39	38	38	37	37	35	40.2	289.5	12.1
	Jul	45	47	48	47	46	46	46	48	48	45	44	42	40	37	34	32	30	28	27	26	40.4	300.2	12.5
	Aug	52	55	57	58	58	59	61	62	60	60	58	55	52	48	44	43	42	41	38	37	52.0	387.1	16.1
	Sept	35	39	39	40	41	42	44	45	45	43	41	36	34	33	33	31	29	28	27	25	36.5	262.6	10.9
	Oct	34	36	36	35	35	35	36	38	37	36	34	34	32	31	28	26	26	24	23	22	31.8	236.8	9.9
	Nov	42	44	44	43	42	42	42	42	40	38	37	33	31	26	22	20	19	18	17	17	32.9	236.7	9.9
	Dec	35	38	40	41	41	42	44	46	46	47	47	47	47	47	47	46	44	42	39	38	43.2	321.5	13.4

131.5
36.0% Exceed
64.0% Meet

EPA
Moderate
Contract
CI 82%
Local Std Dev

E-coli - Percent of Time > 473 MPN/100ml

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
Avg 74-78	Jan	22	24	24	25	25	24	25	25	25	24	24	24	23	23	22	22	22	21	21	20	23.3	173.2	7.2
	Feb	17	18	19	19	18	18	19	20	20	20	18	17	17	17	16	16	16	15	15	15	17.5	117.5	4.9
	Mar	22	24	25	25	25	25	27	28	28	27	26	25	25	25	24	23	22	23	22	21	24.6	183.0	7.6
	April	24	25	25	25	23	23	23	24	24	23	23	22	21	21	20	19	19	18	18	18	21.9	157.6	6.6
	May	30	32	33	34	34	34	35	37	37	36	34	31	29	26	26	25	24	23	22	21	30.2	225.0	9.4
	June	30	33	35	35	36	36	37	38	38	37	34	34	33	32	32	31	30	29	29	28	33.3	239.6	10.0
	Jul	38	41	42	40	38	36	37	38	37	36	35	33	31	28	26	25	23	22	20	19	32.3	240.1	10.0
	Aug	47	49	50	51	51	50	50	50	50	47	44	40	38	37	36	33	32	30	29	27	42.0	312.6	13.0
	Sept	28	31	34	34	33	34	36	36	34	31	31	29	28	27	25	23	22	20	18	17	28.5	205.3	8.6
	Oct	29	30	31	31	30	30	30	31	30	29	28	27	25	24	22	21	19	19	18	16	26.0	193.3	8.1
	Nov	34	35	35	35	34	32	31	32	30	26	23	21	19	17	15	14	13	12	11	11	24.1	173.5	7.2
	Dec	31	33	34	34	34	34	35	38	38	37	36	35	35	34	32	31	30	29	28	27	33.3	247.8	10.3

102.9
28.2% Exceed
71.8% Meet

E-Coli - Monthly Geometric Mean (#/100ml)

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Average	Peak	
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
Avg 74-78	Jan	106	122	126	124	121	120	127	133	133	130	128	126	125	122	119	116	113	109	107	104	120.5	133.1	
	Feb	80	89	93	94	93	94	100	105	105	102	101	99	97	95	92	90	88	86	84	82	93.3	105.0	
	Mar	93	107	112	113	112	117	129	138	141	138	137	135	134	131	127	124	120	116	113	110	122.3	140.7	
	April	114	122	125	124	123	123	128	133	132	130	128	126	124	121	118	116	113	109	107	105	121.0	132.5	
	May	229	261	274	273	267	265	274	283	279	266	252	238	225	211	198	185	173	163	154	146	230.8	283.0	
	June	181	203	214	215	211	213	226	239	239	232	223	213	206	196	186	177	168	160	154	148	200.3	239.3	
	Jul	315	352	356	342	323	310	312	315	302	281	260	241	225	208	190	175	162	150	141	132	254.6	356.3	
	Aug	499	572	593	575	543	517	507	498	470	430	393	359	332	304	279	257	238	223	210	199	399.8	593.1	
	Sept	217	249	257	248	238	238	250	260	254	236	220	206	195	181	165	150	137	128	121	114	203.2	260.0	
	Oct	165	180	179	169	157	150	153	157	151	140	129	120	113	106	97	90	83	77	74	71	128.0	180.2	160 days>126
	Nov	255	274	264	244	221	204	195	188	174	157	142	129	117	107	98	89	81	75	70	66	157.6	273.9	240 Total Days
	Dec	158	190	207	214	215	220	235	249	251	246	242	237	234	228	220	211	201	192	183	174	215.3	250.6	33.3% Compliance

Illness Rate per 1,000 Swimmers based on E-Coli - Monthly Geometric Mean

Risk Assessment

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	% of Swimmers Average	Peak
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8		
Avg 74-78	Jan	7.3	7.9	8.0	8.0	7.8	7.8	8.0	8.2	8.2	8.1	8.1	8.0	8.0	7.9	7.8	7.7	7.6	7.4	7.3	7.2	0.78%	0.82%
	Feb	6.1	6.6	6.8	6.8	6.8	6.8	7.1	7.3	7.3	7.2	7.1	7.0	6.9	6.8	6.7	6.6	6.5	6.4	6.3	6.2	0.68%	0.73%
	Mar	6.8	7.3	7.5	7.5	7.5	7.7	8.1	8.4	8.5	8.4	8.3	8.3	8.3	8.2	8.0	7.9	7.8	7.7	7.6	7.4	0.79%	0.85%
	April	7.6	7.9	8.0	8.0	7.9	7.9	8.1	8.2	8.2	8.1	8.1	8.0	7.9	7.8	7.7	7.7	7.6	7.4	7.4	7.3	0.78%	0.82%
	May	10.5	11.0	11.2	11.2	11.1	11.0	11.2	11.3	11.2	11.0	10.8	10.6	10.4	10.1	9.8	9.6	9.3	9.1	8.8	8.6	1.04%	1.13%
	June	9.5	10.0	10.2	10.2	10.1	10.1	10.4	10.6	10.6	10.5	10.3	10.2	10.0	9.8	9.6	9.4	9.2	9.0	8.8	8.7	0.99%	1.06%
	Jul	11.7	12.2	12.2	12.1	11.8	11.7	11.7	11.7	11.6	11.3	11.0	10.7	10.4	10.1	9.7	9.3	9.0	8.7	8.5	8.2	1.07%	1.22%
	Aug	13.6	14.2	14.3	14.2	14.0	13.8	13.7	13.6	13.4	13.0	12.6	12.3	12.0	11.6	11.2	10.9	10.6	10.3	10.1	9.9	1.25%	1.43%
	Sept	10.2	10.8	10.9	10.8	10.6	10.6	10.8	11.0	10.9	10.6	10.3	10.0	9.8	9.5	9.1	8.7	8.3	8.1	7.8	7.6	0.98%	1.10%
	Oct	9.1	9.5	9.4	9.2	8.9	8.7	8.8	8.9	8.7	8.4	8.1	7.8	7.6	7.3	6.9	6.6	6.3	6.0	5.8	5.6	0.79%	0.95%
	Nov	10.9	11.2	11.0	10.7	10.3	10.0	9.8	9.6	9.3	8.9	8.5	8.1	7.7	7.3	7.0	6.6	6.2	5.9	5.6	5.4	0.85%	1.12%
	Dec	8.9	9.7	10.0	10.2	10.2	10.3	10.6	10.8	10.8	10.7	10.7	10.6	10.5	10.4	10.3	10.1	9.9	9.7	9.5	9.3	1.02%	1.08%

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City of Richmond, Virginia
Department of Public Utilities
CSO Disinfection Report

James River Water Quality Model Results

Alternative B - Phase II CSO Controls

Greeley and Hansen LLC
June 2005

State WQS
CI 75%
State Std Dev

E-Coli - Percent of Time > 235 MPN/100ml

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Reach Average	Hrs/mo	days/yr
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
Avg	Jan	23	25	25	24	24	23	24	27	27	27	27	26	26	25	25	24	24	24	23	22	24.7	184.0	7.7
74-78	Feb	20	22	23	22	21	21	23	24	24	23	22	21	20	19	18	17	17	17	17	17	20.3	136.7	5.7
	Mar	24	26	27	27	26	27	29	32	33	32	32	31	31	30	29	28	27	26	25	24	28.3	210.3	8.8
	April	30	30	30	29	28	29	29	31	31	29	28	27	26	26	25	24	24	23	22	22	27.1	195.2	8.1
	May	35	36	38	38	37	37	40	43	43	42	40	39	38	37	35	32	31	30	28	27	36.2	269.5	11.2
	June	33	35	36	36	36	35	36	38	38	38	38	38	38	37	37	35	34	32	31	30	35.5	255.8	10.7
	Jul	35	37	38	38	37	37	40	43	42	40	38	37	35	33	32	31	29	28	27	24	35.1	261.0	10.9
	Aug	46	49	52	50	49	48	50	53	53	50	48	46	44	41	40	39	37	36	34	31	44.8	333.4	13.9
	Sept	31	33	34	34	34	34	35	37	37	35	34	33	33	31	30	28	27	26	25	23	31.7	228.0	9.5
	Oct	34	35	36	35	34	33	35	36	36	34	34	32	31	29	28	26	24	22	21	20	30.8	228.8	9.5
	Nov	34	34	34	32	31	28	30	33	32	29	28	26	24	22	20	19	18	17	16	15	26.1	187.9	7.8
	Dec	34	36	36	36	36	36	38	41	41	41	41	41	41	41	40	39	39	37	36	35	38.3	285.2	11.9

115.7
31.7% Exceed
68.3% Meet

State WQS
CI 75%
Local Std Dev

E-Coli - Percent of Time >334 MPN/100ml

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
Avg	Jan	18	19	19	19	19	18	20	21	20	21	20	20	19	18	18	18	17	17	17	16	18.8	139.7	5.8
74-78	Feb	16	17	17	17	17	16	16	18	17	17	17	16	15	15	14	14	14	13	13	12	15.6	104.9	4.4
	Mar	21	23	24	24	24	23	24	26	27	25	25	24	23	23	23	23	22	20	19	18	23.1	171.8	7.2
	April	22	23	23	23	23	23	23	24	23	23	23	22	22	21	21	19	19	18	18	18	21.5	155.0	6.5
	May	26	28	28	28	28	28	30	33	34	32	32	30	28	26	25	23	22	21	19	18	27.0	200.5	8.4
	June	26	28	30	30	30	32	33	35	36	34	33	33	32	30	29	28	27	26	25	24	30.2	217.3	9.1
	Jul	30	32	32	32	32	31	32	34	34	34	33	31	29	27	25	24	22	22	21	19	28.8	213.9	8.9
	Aug	39	42	45	45	43	43	42	42	41	40	39	37	35	33	31	31	29	28	27	26	36.8	274.2	11.4
	Sept	23	25	27	27	27	28	31	31	31	31	30	29	28	26	24	23	21	20	18	17	25.9	186.8	7.8
	Oct	27	29	29	29	28	28	29	32	32	31	30	28	25	23	21	20	19	19	17	17	25.7	191.5	8.0
	Nov	29	29	29	27	25	23	24	25	23	21	18	17	16	15	15	14	13	13	12	12	20.0	144.1	6.0
	Dec	28	30	31	32	31	31	33	35	35	35	35	35	35	34	32	31	29	27	25	23	31.5	234.2	9.8

93.1
25.5% Exceed
74.5% Meet

EPA
Moderate
Contract
CI 82%
State Std Dev

E-coli - Percent of Time > 298 MPN/100ml

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
Avg	Jan	19	20	21	20	20	19	21	23	23	23	22	21	21	21	21	20	19	19	19	18	20.5	152.3	6.3
74-78	Feb	16	18	18	18	18	17	18	20	19	19	18	17	17	16	16	15	15	15	14	14	17.0	114.2	4.8
	Mar	22	24	25	25	25	25	27	29	30	28	27	26	26	26	25	25	24	24	22	22	25.3	187.9	7.8
	April	25	25	25	24	24	23	24	25	25	24	23	23	22	22	21	21	21	20	21	19	22.9	164.9	6.9
	May	29	30	32	31	31	31	33	36	36	35	34	34	32	28	27	25	24	23	21	20	29.6	220.1	9.2
	June	27	30	32	32	32	33	34	36	37	36	35	35	34	33	31	29	28	27	27	26	31.7	228.2	9.5
	Jul	32	33	34	33	33	33	34	36	37	35	34	33	32	30	28	26	25	23	22	20	30.7	228.0	9.5
	Aug	40	44	46	47	46	45	46	47	44	42	41	39	38	36	34	33	31	30	29	28	39.3	292.6	12.2
	Sept	26	29	29	29	29	30	32	33	33	32	31	31	30	28	26	25	23	21	19	19	27.7	199.7	8.3
	Oct	30	31	31	31	29	29	30	34	33	32	31	30	29	26	23	21	20	20	19	18	27.3	202.9	8.5
	Nov	30	31	30	29	27	26	25	28	27	25	22	19	19	17	16	14	14	13	13	12	21.9	157.5	6.6
	Dec	30	31	33	34	34	34	35	37	37	37	37	37	37	36	36	35	33	30	29	27	34.0	252.8	10.5

100.0
27.4% Exceed
72.6% Meet

EPA
Moderate
Contract
CI 82%
Local Std Dev

E-coli - Percent of Time > 473 MPN/100ml

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
Avg	Jan	15	17	16	15	15	14	15	16	16	15	14	14	14	14	13	13	13	12	11	10	14.1	104.8	4.4
74-78	Feb	11	11	11	11	10	10	10	11	11	10	9	9	9	9	9	9	9	9	9	8	9.7	65.2	2.7
	Mar	16	18	19	18	18	18	20	21	21	19	19	18	18	18	17	16	15	15	15	15	17.8	132.2	5.5
	April	21	21	21	21	19	19	19	20	20	19	19	18	17	16	16	15	14	14	13	13	17.8	128.1	5.3
	May	21	22	23	23	22	22	22	25	24	24	22	20	18	17	16	16	15	15	15	14	19.9	147.8	6.2
	June	24	26	27	26	27	27	29	31	31	30	29	28	28	26	24	24	23	22	22	21	26.2	188.8	7.9
	Jul	27	28	29	27	26	25	26	28	28	26	26	24	24	23	22	21	19	16	16	15	23.8	177.0	7.4
	Aug	33	35	36	35	33	33	34	35	35	33	32	29	28	27	25	24	24	22	22	21	29.7	220.6	9.2
	Sept	19	21	22	23	22	22	25	27	28	27	25	23	22	20	19	18	16	15	14	13	21.0	151.3	6.3
	Oct	22	24	25	25	24	24	24	26	26	25	23	20	19	19	18	17	16	16	15	13	21.0	156.3	6.5
	Nov	21	21	20	19	18	17	16	17	16	16	15	14	13	11	10	10	9	9	8	7	14.4	103.5	4.3
	Dec	24	25	26	26	26	26	28	29	30	28	27	26	25	24	22	21	20	19	18	17	24.5	182.4	7.6

73.3
20.1% Exceed
79.9% Meet

E-Coli - Monthly Geometric Mean (#/100ml)

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Reach Average	Peak	
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
Avg	Jan	80	90	93	91	88	87	93	99	100	97	95	93	92	89	86	83	80	77	75	73	88.1	99.8	
74-78	Feb	62	67	69	69	67	67	71	75	75	73	71	70	69	67	65	63	61	59	57	55	66.6	74.7	
	Mar	74	84	87	86	84	87	97	104	106	103	100	98	97	94	90	88	85	82	80	77	90.1	105.7	
	April	99	104	106	105	103	102	106	110	110	107	105	103	102	99	97	94	92	90	88	87	100.5	110.2	
	May	152	168	177	177	172	173	185	196	197	189	181	173	164	154	144	135	127	119	113	108	160.3	196.7	
	June	140	154	161	161	156	157	168	179	180	174	166	159	153	146	137	130	123	116	111	107	148.9	179.9	
	Jul	181	200	203	196	185	183	194	203	199	186	174	162	152	141	130	119	111	104	99	93	160.8	203.4	
	Aug	280	318	332	323	304	295	303	310	301	279	256	236	220	203	186	172	159	150	143	137	245.4	332.5	
	Sept	123	137	141	135	129	131	145	157	157	148	138	131	125	117	107	99	91	87	83	81	123.0	156.7	
	Oct	123	134	136	129	120	116	121	127	123	116	107	100	95	88	81	74	69	64	61	59	102.2	136.0	104 days>126
	Nov	136	145	142	132	120	113	115	118	113	103	94	85	78	71	65	59	54	51	48	46	94.3	144.5	240 Total Days
	Dec	113	135	146	149	148	150	163	175	176	173	169	165	163	158	152	145	138	131	125	119	149.6	176.5	56.7% Compliance

Illness Rate per 1,000 Swimmers based on E-Coli - Monthly Geometric Mean

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Risk Assessment % of Swimmers Average	Peak
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8		
Avg	Jan	6.2	6.6	6.8	6.7	6.5	6.5	6.8	7.0	7.1	6.9	6.9	6.8	6.7	6.6	6.5	6.3	6.2	6.0	5.9	5.8	0.65%	0.71%
74-78	Feb	5.1	5.4	5.6	5.5	5.4	5.5	5.7	5.9	5.9	5.8	5.7	5.6	5.5	5.4	5.3	5.2	5.1	4.9	4.8	4.7	0.54%	0.59%
	Mar	5.8	6.3	6.5	6.4	6.4	6.5	6.9	7.2	7.3	7.2	7.1	7.0	6.9	6.8	6.7	6.5	6.4	6.2	6.1	6.0	0.66%	0.73%
	April	7.0	7.2	7.3	7.3	7.2	7.2	7.3	7.5	7.5	7.3	7.3	7.2	7.1	7.0	6.9	6.8	6.7	6.6	6.6	6.5	0.71%	0.75%
	May	8.8	9.2	9.4	9.4	9.3	9.3	9.6	9.8	9.8	9.7	9.5	9.3	9.1	8.8	8.6	8.3	8.0	7.8	7.6	7.4	0.89%	0.98%
	June	8.4	8.8	9.0	9.0	8.9	8.9	9.2	9.4	9.5	9.3	9.1	9.0	8.8	8.6	8.4	8.1	7.9	7.7	7.5	7.3	0.86%	0.95%
	Jul	9.5	9.9	10.0	9.8	9.6	9.5	9.8	10.0	9.9	9.6	9.3	9.0	8.8	8.5	8.1	7.8	7.5	7.2	7.0	6.8	0.89%	1.00%
	Aug	11.3	11.8	12.0	11.8	11.6	11.5	11.6	11.7	11.6	11.3	10.9	10.6	10.3	10.0	9.6	9.3	9.0	8.7	8.5	8.3	1.06%	1.20%
	Sept	7.9	8.4	8.5	8.3	8.1	8.2	8.6	8.9	8.9	8.7	8.4	8.2	8.0	7.7	7.4	7.0	6.7	6.5	6.3	6.2	0.78%	0.89%
	Oct	7.9	8.3	8.3	8.1	7.8	7.7	7.9	8.0	7.9	7.7	7.3	7.1	6.8	6.5	6.2	5.9	5.5	5.2	5.1	4.9	0.70%	0.83%
	Nov	8.3	8.6	8.5	8.2	7.8	7.6	7.6	7.7	7.5	7.2	6.8	6.4	6.0	5.7	5.3	4.9	4.6	4.3	4.1	3.9	0.65%	0.86%
	Dec	7.6	8.3	8.6	8.7	8.7	8.7	9.0	9.3	9.4	9.3	9.2	9.1	9.1	8.9	8.8	8.6	8.4	8.2	8.0	7.8	0.87%	0.94%

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City of Richmond, Virginia
Department of Public Utilities
CSO Disinfection Report

James River Water Qualtiy Model Results

Alternative E - From CSO LTCP Assumed 80% Bacteriological Load Reduction at Shockoe

Greeley and Hansen LLC
June 2005

State WQS
CI 75%
State Std Dev

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Reach		
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8	Average	Hrs/mo	days/yr
E-Coli - Percent of Time > 235 MPN/100ml																								
Avg 74-78	Jan	15	18	18	17	17	16	18	21	22	22	22	20	20	18	18	18	17	17	16	16	18.4	136.9	5.7
	Feb	17	18	19	17	17	17	19	20	20	19	19	19	18	18	17	16	16	16	15	15	17.6	118.3	4.9
	Mar	19	21	22	22	22	21	24	27	28	27	26	25	25	24	23	22	21	20	19	19	22.8	169.6	7.1
	April	27	29	28	27	26	26	26	28	28	26	26	25	23	23	23	22	21	21	20	19	24.8	178.3	7.4
	May	30	31	33	32	32	32	35	38	38	36	35	34	33	32	29	27	26	25	25	25	31.4	233.4	9.7
	June	28	29	30	31	30	30	32	34	36	35	35	34	34	33	31	30	28	27	26	25	30.9	222.2	9.3
	Jul	28	30	31	31	30	30	34	37	36	34	32	31	29	28	27	24	22	20	19	19	28.6	213.0	8.9
	Aug	36	40	43	41	40	40	44	45	45	45	42	39	37	34	32	31	29	27	26	23	36.8	274.0	11.4
	Sept	22	25	27	26	25	25	26	28	29	28	27	26	26	23	22	21	20	19	18	17	24.0	172.4	7.2
	Oct	25	27	27	28	26	27	29	32	31	30	30	27	26	26	25	24	20	19	18	17	25.7	191.4	8.0
	Nov	25	26	27	26	25	23	25	28	27	25	23	22	20	19	18	16	15	14	12	12	21.4	154.4	6.4
	Dec	24	26	28	29	28	28	31	33	32	32	32	31	31	30	28	26	25	24	23	23	28.2	209.6	8.7

94.7
26.0% Exceed
74.0% Meet

State WQS
CI 75%
Local Std Dev

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
E-Coli - Percent of Time >334 MPN/100ml																								
Avg 74-78	Jan	11	12	12	12	11	11	13	16	16	16	15	15	14	13	12	12	12	12	11	11	12.9	95.6	4.0
	Feb	13	14	14	13	14	13	13	15	15	15	15	14	14	14	13	13	13	12	11	10	13.3	89.7	3.7
	Mar	17	18	18	18	18	17	19	21	21	20	19	19	18	17	17	17	15	14	13	13	17.5	130.0	5.4
	April	20	21	22	21	21	21	21	22	22	21	21	20	20	19	18	17	17	15	16	15	19.5	140.1	5.8
	May	22	23	24	23	24	23	25	27	28	27	26	25	23	21	20	19	18	18	18	17	22.5	167.3	7.0
	June	22	24	25	25	25	25	28	30	31	31	30	29	28	26	25	24	23	22	22	21	25.6	184.6	7.7
	Jul	24	25	26	25	24	24	26	28	28	27	26	24	22	21	17	16	14	14	13	12	21.9	162.8	6.8
	Aug	28	31	34	33	31	31	33	36	37	33	32	29	28	26	24	23	22	20	18	17	28.2	210.1	8.8
	Sept	16	17	19	18	18	19	22	25	26	24	23	22	20	19	17	15	14	13	12	11	18.5	133.3	5.6
	Oct	19	20	21	21	21	21	24	27	27	26	25	23	21	19	18	17	16	15	14	13	20.4	152.1	6.3
	Nov	21	21	22	19	18	17	19	21	19	18	15	14	13	13	10	10	9	9	9	9	15.3	110.3	4.6
	Dec	19	21	22	23	21	21	24	27	27	26	25	24	22	20	19	17	16	14	13	12	20.7	153.7	6.4

72.1
19.7% Exceed
80.3% Meet

EPA
Moderate
Contract
CI 82%
State Std Dev

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
E-coli - Percent of Time > 298 MPN/100ml																								
Avg 74-78	Jan	12	13	14	13	13	13	15	18	18	17	16	16	16	15	15	14	13	13	13	12	14.4	107.1	4.5
	Feb	13	14	14	14	14	13	15	17	17	17	16	15	15	15	14	14	14	14	13	13	14.6	98.2	4.1
	Mar	17	18	20	19	19	19	21	23	23	22	21	21	21	20	19	19	19	18	16	16	19.6	145.9	6.1
	April	21	22	22	22	21	21	22	23	23	23	22	21	20	20	20	19	18	18	18	16	20.7	149.3	6.2
	May	25	27	28	27	26	26	28	31	31	29	29	28	26	23	22	21	21	20	19	19	25.3	188.1	7.8
	June	23	25	26	27	26	27	30	32	32	32	32	31	29	27	26	25	24	24	23	23	27.2	195.5	8.1
	Jul	26	28	29	27	26	26	29	30	31	29	28	27	25	24	20	19	18	16	14	13	24.2	180.1	7.5
	Aug	30	34	37	37	35	35	38	40	39	38	34	32	30	28	27	26	23	21	20	19	31.1	231.2	9.6
	Sept	19	21	21	20	19	20	24	26	27	25	24	23	21	21	20	18	16	15	14	12	20.3	146.0	6.1
	Oct	21	22	23	22	22	23	25	28	28	28	27	26	25	23	19	18	17	16	16	15	22.2	165.3	6.9
	Nov	23	24	23	23	20	20	21	23	22	20	18	16	16	15	13	11	10	10	10	9	17.3	124.5	5.2
	Dec	20	22	24	25	24	24	27	29	29	28	27	26	25	24	22	21	20	18	17	15	23.4	174.3	7.3

79.4
21.8% Exceed
78.2% Meet

EPA
Moderate
Contract
CI 82%
Local Std Dev

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
E-coli - Percent of Time > 473 MPN/100ml																								
Avg 74-78	Jan	9	10	9	9	8	8	9	12	11	10	9	9	10	9	8	8	8	7	7	7	8.7	65.0	2.7
	Feb	9	9	9	9	8	8	8	9	9	8	8	7	7	8	7	7	7	7	7	7	7.9	53.3	2.2
	Mar	13	14	14	13	13	13	15	17	16	15	14	14	13	12	12	11	11	11	11	10	13.1	97.1	4.0
	April	18	19	19	18	17	17	17	18	18	17	17	16	15	14	13	12	12	11	11	11	15.6	112.7	4.7
	May	18	18	19	18	17	17	17	20	20	19	18	16	15	14	14	14	13	13	12	12	16.2	120.4	5.0
	June	20	21	21	22	22	22	24	26	27	26	24	22	22	21	20	20	19	19	19	18	21.7	156.5	6.5
	Jul	20	21	22	20	19	17	19	22	22	20	19	17	15	13	12	11	10	9	9	8	16.2	120.8	5.0
	Aug	22	23	23	23	22	22	24	27	28	27	25	23	22	21	19	18	17	15	13	12	21.2	157.5	6.6
	Sept	12	14	15	15	14	14	18	21	21	19	16	15	14	13	12	11	10	9	9	8	14.0	100.6	4.2
	Oct	16	17	18	18	17	16	18	20	20	19	16	15	14	14	13	12	12	12	11	10	15.4	114.6	4.8
	Nov	15	15	13	13	13	12	12	14	14	13	12	11	9	8	7	7	6	6	6	6	10.6	76.6	3.2
	Dec	15	15	16	15	15	15	16	18	18	17	15	14	12	12	11	10	10	9	9	9	13.6	101.0	4.2

53.2
14.6% Exceed
85.4% Meet

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Reach	
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8	Average	Peak
E-Coli - Monthly Geometric Mean (#/100ml)																							
Avg 74-78	Jan	56	66	69	68	66	66	73	79	80	78	77	75	73	71	68	65	63	60	58	57	68.4	80.1
	Feb	53	58	60	59	58	58	62	65	65	63	62	61	60	59	57	55	53	52	50	48	57.9	65.1
	Mar	56	64	67	66	64	66	74	80	82	80	78	77	76	74	72	69	67	65	63	62	70.1	81.9
	April	87	91	93	92	89	89	93	98	98	95	94	92	91	89	87	85	83	80	79	77	89.0	97.6
	May	124	137	145	145	142	143	155	167	168	162	156	149	142	134	125	117	110	104	99	95	135.9	168.0
	June	113	123	129	128	125	126	135	145	146	141	135	129	124	118	111	106	100	94	90	87	120.3	146.3
	Jul	112	124	130	126	118	119	131	142	141	132	122	113	105	97	87	79	73	67	64	61	107.1	141.9
	Aug	160	182	193	189	178	177	189	201	199	188	174	161	151	140	129	118	109	102	97	92	156.5	201.0
	Sept	74	83	87	84	80	83	94	104	105	98	92	87	84	78	72	66	61	59	57	55	80.1	104.6
	Oct	80	89	92	89	82	81	87	94	92	87	81	75	72	66	60	55	51	48	46	45	73.7	93.6
	Nov	83	91	94	89	82	81	87	92	91	84	78	72	67	62	57	52	48	45	43	42	71.9	93.7
	Dec	72	86	95	96	94	96	106	115	117	114	111	108	106	102	97	92	87	82	78	75	96.4	116.9

41 days>126
240 Total Days
82.9% Compliance

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Risk Assessment % of Swimmers	
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8	Average	Peak
Illness Rate per 1,000 Swimmers based on E-Coli - Monthly Geometric Mean																							
Avg 74-78	Jan	4.7	5.3	5.6	5.5	5.4	5.4	5.8	6.1	6.2	6.1	6.0	5.9	5.8	5.7	5.5	5.3	5.1	5.0	4.8	4.7	0.55%	0.62%
	Feb	4.5	4.8	5.0	4.9	4.8	4.9	5.1	5.3	5.3	5.2	5.1	5.1	5.0	4.9	4.8	4.6	4.5	4.4	4.2	4.1	0.48%	0.53%
	Mar	4.7	5.2	5.4	5.4	5.3	5.4	5.8	6.2	6.2	6.1	6.0	6.0	5.9	5.8	5.7	5.6	5.4	5.3	5.2	5.1	0.56%	0.62%
	April	6.5	6.7	6.8	6.7	6.6	6.6	6.8	7.0	7.0	6.9	6.8	6.7	6.7	6.6	6.5	6.4	6.3	6.2	6.1	6.0	0.66%	0.70%
	May	7.9	8.3	8.6	8.6	8.5	8.5	8.9	9.2	9.2	9.0	8.9	8.7	8.5	8.3	8.0	7.7	7.5	7.2	7.0	6.8	0.83%	0.92%
	June	7.6	7.9	8.1	8.1	8.0	8.0	8.3	8.6	8.6	8.5	8.3	8.1	7.9	7.7	7.5	7.3	7.0	6.8	6.7	6.5	0.78%	0.86%
	Jul	7.5	8.0	8.1	8.0	7.7	7.8	8.2	8.5	8.5	8.2	7.9	7.6	7.3	6.9	6.5	6.1	5.8	5.4	5.2	5.0	0.72%	0.85%
	Aug	9.0	9.5	9.8	9.7	9.4	9.4	9.7	9.9	9.9	9.6	9.3	9.0	8.8	8.4	8.1	7.7	7.4	7.2	6.9	6.7	0.88%	0.99%
	Sept	5.8	6.3	6.5	6.3	6.1	6.3	6.8	7.2	7.2	7.0	6.7	6.5	6.3	6.0	5.7	5.4	5.1	4.9	4.8	4.6	0.61%	0.72%
	Oct	6.2	6.6	6.7	6.6	6.3	6.2	6.5	6.8	6.7	6.5	6.2	5.9	5.7	5.4	5.0	4.7	4.3	4.1	3.9	3.8	0.57%	0.68%
	Nov	6.3	6.7	6.8	6.6	6.3	6.2	6.5	6.7	6.7	6.4	6.0	5.7	5.4	5.1	4.7	4.4	4.1	3.8	3.6	3.5	0.56%	0.68%
	Dec	5.7	6.4	6.8	6.9	6.8	6.9	7.3	7.6	7.7	7.6	7.5	7.4	7.3	7.2	7.0	6.7	6.5	6.3	6.1	5.9	0.69%	0.77%

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City of Richmond, Virginia
Department of Public Utilities
CSO Disinfection Report

James River Water Qualtiy Model Results

Alternative G - Complete City-Wide Separation

Greeley and Hansen LLC
June 2005

State WQS
CI 75%
State Std Dev

E-Coli - Percent of Time > 235 MPN/100ml

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Reach Average	Hrs/mo	days/yr
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
Avg 74-78	Jan	16	19	20	20	20	18	20	23	24	23	23	22	20	20	19	19	18	18	17	17	19.8	147.4	6.1
	Feb	18	19	20	19	19	20	20	22	22	21	22	21	20	20	18	18	17	17	16	16	19.3	129.9	5.4
	Mar	20	22	23	22	22	22	25	27	28	27	26	26	25	25	24	23	22	22	21	20	23.5	175.0	7.3
	April	28	29	29	27	26	25	26	28	28	26	25	25	23	23	23	22	22	21	20	20	24.6	177.5	7.4
	May	32	34	35	35	34	34	38	41	40	40	38	36	35	33	31	28	27	26	25	25	33.4	248.2	10.3
	June	30	32	32	32	32	31	33	35	35	35	35	35	34	33	32	30	29	27	26	25	31.7	228.2	9.5
	Jul	30	32	33	33	30	31	33	36	35	33	31	27	26	25	21	20	19	18	16	15	27.1	201.6	8.4
	Aug	36	38	39	37	35	34	37	40	41	41	39	36	33	31	29	28	27	25	25	23	33.7	250.7	10.4
	Sept	26	28	29	28	26	26	28	30	30	29	27	26	25	22	21	20	18	17	16	14	24.3	174.8	7.3
	Oct	27	29	29	28	28	28	30	32	31	30	29	27	26	25	25	23	20	18	17	17	25.9	193.0	8.0
	Nov	27	28	28	27	26	24	27	30	29	27	25	24	22	21	20	18	17	15	13	12	23.0	165.3	6.9
	Dec	26	27	28	29	29	29	31	34	34	33	32	31	31	30	28	25	24	23	22	22	28.3	210.9	8.8

95.9
26.3% Exceed
73.7% Meet

State WQS
CI 75%
Local Std Dev

E-Coli - Percent of Time >334 MPN/100ml

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
Avg 74-78	Jan	11	13	13	13	12	12	14	17	17	16	16	15	14	13	13	12	12	12	11	11	13.4	99.7	4.2
	Feb	14	15	16	15	15	14	14	16	16	16	15	14	14	14	13	13	12	11	10	9	14.0	93.8	3.9
	Mar	17	19	18	18	17	17	18	21	21	20	19	19	18	18	18	17	16	15	14	13	17.6	131.3	5.5
	April	20	21	21	20	20	20	20	21	21	21	20	20	19	19	19	17	16	16	15	15	19.0	137.0	5.7
	May	24	25	27	25	24	24	25	28	28	27	26	25	22	21	20	18	18	17	17	16	22.9	170.2	7.1
	June	24	26	28	28	28	28	30	31	31	30	30	29	27	25	24	23	22	21	20	20	26.2	188.5	7.9
	Jul	23	25	25	24	23	23	26	28	27	25	23	21	18	16	14	12	11	10	9	8	19.6	146.0	6.1
	Aug	28	31	32	30	29	28	29	32	32	30	27	26	25	23	21	19	18	18	17	16	25.5	189.5	7.9
	Sept	19	20	21	20	18	19	22	25	25	24	22	21	19	18	16	15	14	12	11	10	18.5	132.9	5.5
	Oct	19	22	22	22	22	22	25	27	27	26	24	23	21	18	17	15	15	15	13	13	20.3	151.2	6.3
	Nov	21	22	22	20	18	17	19	21	19	18	15	14	13	13	10	10	9	9	8	8	15.5	111.6	4.7
	Dec	20	22	22	22	21	21	24	26	27	26	26	25	22	21	19	17	16	15	14	13	21.0	156.3	6.5

71.2
19.5% Exceed
80.5% Meet

EPA
Moderate
Contract
CI 82%
State Std Dev

E-coli - Percent of Time > 298 MPN/100ml

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
Avg 74-78	Jan	12	14	16	15	15	14	16	19	20	18	18	17	17	16	15	15	13	13	13	13	15.5	115.2	4.8
	Feb	14	16	16	16	15	15	16	18	18	17	17	16	16	15	15	15	15	14	14	13	15.6	105.0	4.4
	Mar	18	20	20	20	19	19	21	23	24	23	22	21	21	21	20	20	19	18	17	16	20.0	149.1	6.2
	April	22	23	22	21	20	20	22	24	23	22	21	21	20	20	19	19	19	18	18	17	20.5	147.8	6.2
	May	27	29	29	29	27	26	29	32	32	30	29	29	26	24	22	21	20	20	18	17	25.7	191.4	8.0
	June	25	27	29	29	29	29	30	32	33	32	32	31	29	28	26	24	24	23	22	22	27.8	200.2	8.3
	Jul	26	27	28	26	25	25	28	30	30	28	25	24	22	19	17	15	14	12	11	9	22.1	164.1	6.8
	Aug	29	33	34	33	30	30	34	35	34	33	29	27	27	25	24	23	21	19	19	18	27.9	207.6	8.6
	Sept	22	23	22	21	20	21	24	26	27	26	24	23	20	20	19	17	15	14	13	11	20.3	146.4	6.1
	Oct	22	24	25	24	23	23	26	28	28	28	26	25	24	22	19	17	16	15	15	15	22.3	165.6	6.9
	Nov	24	26	24	23	21	20	21	24	23	20	19	17	17	15	13	11	10	10	9	9	17.8	127.8	5.3
	Dec	21	23	24	24	23	24	26	29	28	28	28	27	26	24	22	22	21	18	17	15	23.5	175.0	7.3

79.0
21.6% Exceed
78.4% Meet

EPA
Moderate
Contract
CI 82%
Local Std Dev

E-coli - Percent of Time > 473 MPN/100ml

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
Avg 74-78	Jan	9	10	9	8	8	7	10	12	12	10	9	8	8	8	7	7	6	6	6	6	8.2	61.3	2.6
	Feb	10	10	10	10	9	8	9	10	10	9	9	8	8	8	8	8	7	7	7	7	8.7	58.4	2.4
	Mar	12	14	14	14	13	13	15	16	16	14	14	13	13	12	12	12	12	11	11	11	13.1	97.7	4.1
	April	18	19	19	18	17	17	17	18	18	17	17	16	15	14	13	12	12	11	11	11	15.4	111.2	4.6
	May	18	19	20	20	18	18	18	20	19	19	18	15	14	13	13	13	13	12	12	12	16.2	120.2	5.0
	June	22	23	24	23	22	22	24	25	26	25	23	22	21	20	19	19	18	18	17	17	21.5	154.6	6.4
	Jul	18	20	21	18	16	14	17	20	20	18	16	11	11	10	9	8	7	6	6	6	13.6	101.1	4.2
	Aug	20	22	22	20	18	18	21	24	24	22	20	18	17	16	14	13	13	12	11	10	17.8	132.8	5.5
	Sept	14	15	16	15	14	14	17	20	20	18	15	13	12	11	10	8	8	7	6	6	13.0	93.3	3.9
	Oct	16	17	18	18	17	17	18	21	20	18	16	15	13	12	11	11	11	11	10	9	14.9	111.0	4.6
	Nov	14	15	14	13	12	12	12	15	14	13	12	11	9	8	7	7	6	6	6	6	10.5	75.8	3.2
	Dec	16	16	17	16	14	14	16	19	18	17	16	14	13	12	11	10	10	10	9	9	13.8	102.9	4.3

50.8
13.9% Exceed
86.1% Meet

E-Coli - Monthly Geometric Mean (#/100ml)

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Reach Average	Peak	
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
Avg 74-78	Jan	59	64	67	67	66	67	75	82	83	81	79	77	74	71	68	64	61	59	57	55	68.7	82.9	
	Feb	55	57	59	58	57	58	61	65	65	63	63	62	61	59	58	56	54	53	51	49	58.2	65.0	
	Mar	59	63	65	65	63	64	71	77	78	76	74	73	72	71	69	67	65	63	62	60	67.9	77.9	
	April	89	92	93	92	89	89	94	99	99	96	95	93	91	88	85	83	80	77	76	74	88.7	98.8	
	May	140	151	157	157	154	155	165	176	176	169	163	156	150	141	132	124	116	108	103	98	144.6	175.8	
	June	126	134	137	135	131	130	138	146	146	140	134	127	122	115	108	102	96	90	86	82	121.3	146.0	
	Jul	109	119	123	119	112	112	124	135	132	122	112	103	95	86	77	69	63	58	54	51	98.7	134.6	
	Aug	129	138	141	136	127	127	140	152	153	146	137	128	121	113	104	95	88	83	79	76	120.7	153.5	
	Sept	82	88	89	85	80	81	90	98	96	88	81	74	70	64	58	53	49	46	43	41	72.9	97.8	
	Oct	84	90	92	89	83	83	92	98	96	90	83	77	73	67	60	55	50	47	45	44	75.0	98.4	41 days>126
	Nov	89	93	94	90	84	83	89	95	93	87	81	75	70	64	59	53	49	45	43	41	73.8	94.8	240 Total Days
	Dec	78	86	91	93	91	94	105	114	116	113	110	106	104	100	95	89	84	79	74	71	94.6	116.0	82.9% Compliance

Illness Rate per 1,000 Swimmers based on E-Coli - Monthly Geometric Mean

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Risk Assessment % of Swimmers Average	Peak
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8		
Avg 74-78	Jan	4.9	5.3	5.4	5.4	5.3	5.4	5.9	6.2	6.3	6.2	6.1	6.0	5.9	5.7	5.5	5.3	5.1	4.9	4.7	4.6	0.55%	0.63%
	Feb	4.6	4.8	4.9	4.8	4.8	4.8	5.1	5.3	5.3	5.2	5.1	5.1	5.0	4.9	4.8	4.7	4.6	4.4	4.3	4.2	0.48%	0.53%
	Mar	4.9	5.2	5.3	5.3	5.2	5.3	5.7	6.0	6.0	5.9	5.8	5.8	5.7	5.7	5.5	5.4	5.3	5.2	5.1	5.0	0.55%	0.60%
	April	6.6	6.7	6.8	6.7	6.6	6.6	6.8	7.0	7.0	6.9	6.8	6.7	6.7	6.5	6.4	6.3	6.2	6.0	5.9	5.8	0.66%	0.70%
	May	8.4	8.7	8.9	8.9	8.8	8.8	9.1	9.4	9.4	9.2	9.1	8.9	8.7	8.5	8.2	7.9	7.7	7.4	7.2	7.0	0.85%	0.94%
	June	8.0	8.3	8.4	8.3	8.2	8.1	8.4	8.6	8.6	8.4	8.2	8.0	7.9	7.6	7.4	7.1	6.9	6.6	6.4	6.3	0.78%	0.86%
	Jul	7.4	7.8	7.9	7.8	7.5	7.5	8.0	8.3	8.2	7.9	7.5	7.2	6.8	6.5	6.0	5.6	5.1	4.8	4.6	4.3	0.68%	0.83%
	Aug	8.1	8.4	8.5	8.3	8.1	8.1	8.4	8.8	8.8	8.6	8.3	8.1	7.9	7.6	7.2	6.9	6.5	6.3	6.1	5.9	0.77%	0.88%
	Sept	6.3	6.5	6.6	6.4	6.2	6.2	6.7	7.0	6.9	6.6	6.2	5.9	5.6	5.2	4.8	4.5	4.1	3.9	3.7	3.5	0.56%	0.70%
	Oct	6.4	6.6	6.7	6.6	6.3	6.3	6.7	7.0	6.9	6.6	6.3	6.0	5.8	5.4	5.0	4.6	4.3	4.0	3.8	3.7	0.57%	0.70%
	Nov	6.6	6.8	6.8	6.6	6.3	6.3	6.6	6.8	6.8	6.5	6.2	5.9	5.6	5.3	4.9	4.5	4.1	3.8	3.6	3.4	0.57%	0.68%
	Dec	6.0	6.5	6.7	6.7	6.7	6.8	7.2	7.6	7.7	7.6	7.4	7.3	7.2	7.1	6.8	6.6	6.3	6.1	5.9	5.6	0.68%	0.77%

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City of Richmond, Virginia
Department of Public Utilities
Phase III CSO Control Program

Funded by U.S. Army Corps of Engineers, Norfolk District
Under Contact No. DACW65-01-C-0052

CSO Disinfection Report

Appendix A
Water Quality Model Results Translated to *E. coli*

Model Runs for UV Disinfection at Shockoe

FINAL REPORT

June 2005

Greeley and Hansen LLC
with LTI, Inc

City of Richmond, Virginia
Department of Public Utilities
CSO Disinfection Report

James River Water Qualtiy Model Results

Alternative E - South Side Disinfection Facility with 500 UV Lamps

Greeley and Hansen LLC
June 2005

State WQS
CI 75%
State Std Dev

E-Coli - Percent of Time > 235 MPN/100ml

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Reach Average	Hrs/mo	days/yr
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
Avg 74-78	Jan	17	19	20	19	18	18	20	22	23	23	23	22	21	20	19	19	18	18	17	17	19.7	146.3	6.1
	Feb	18	19	20	19	18	18	20	21	21	20	20	20	19	19	17	17	17	16	16	16	18.5	124.3	5.2
	Mar	20	22	24	23	23	23	26	29	29	28	28	28	27	26	25	25	23	22	22	21	24.8	184.3	7.7
	April	28	29	29	28	27	27	28	29	29	27	26	26	25	24	24	23	23	22	21	21	25.8	185.4	7.7
	May	32	33	35	35	34	34	37	40	40	39	38	37	35	34	32	29	28	27	26	25	33.5	248.9	10.4
	June	30	32	33	34	34	33	35	36	37	36	36	36	36	35	34	32	30	29	27	27	33.2	238.9	10.0
	Jul	31	33	34	34	34	33	36	39	38	37	35	33	32	30	29	28	26	24	23	21	31.6	234.9	9.8
	Aug	42	45	48	47	46	45	47	48	48	48	45	42	40	38	38	36	35	34	31	28	41.6	309.2	12.9
	Sept	25	28	29	28	27	28	31	32	33	32	31	30	29	26	24	23	22	21	21	20	27.1	195.0	8.1
	Oct	29	31	31	31	30	31	33	34	34	32	32	29	27	27	26	24	21	20	20	19	28.0	208.4	8.7
	Nov	27	28	29	27	27	25	27	29	28	26	24	23	21	20	19	17	16	15	14	12	22.8	164.1	6.8
	Dec	28	30	31	33	32	32	33	36	35	35	35	35	35	35	33	32	31	29	28	27	32.2	239.7	10.0

103.3
28.3% Exceed
71.7% Meet

State WQS
CI 75%
Local Std Dev

E-Coli - Percent of Time >334 MPN/100ml

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Reach Average	Hrs/mo	days/yr
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
Avg 74-78	Jan	13	15	15	14	13	13	15	17	17	17	16	16	15	14	13	13	13	13	12	12	14.2	105.4	4.4
	Feb	14	15	15	15	15	14	15	16	16	15	15	15	14	15	14	14	13	13	12	10	14.2	95.6	4.0
	Mar	18	20	20	20	20	19	21	23	23	23	21	21	20	20	20	19	18	17	16	15	19.7	146.2	6.1
	April	21	22	22	22	22	22	22	23	23	22	22	22	21	20	20	18	18	17	17	17	20.6	148.4	6.2
	May	24	25	26	26	26	26	28	31	31	30	28	27	25	24	22	21	20	19	19	18	24.8	184.3	7.7
	June	24	26	27	28	28	29	32	33	34	33	32	32	30	29	28	27	25	24	24	23	28.4	204.6	8.5
	Jul	27	28	29	29	28	28	30	32	32	31	31	28	26	25	23	21	19	18	18	17	26.0	193.3	8.1
	Aug	35	38	41	40	38	36	38	40	40	39	37	35	32	30	28	27	26	25	24	23	33.6	250.0	10.4
	Sept	19	20	22	22	22	22	25	28	28	27	26	25	22	22	21	18	17	17	15	14	21.6	155.8	6.5
	Oct	22	24	25	25	25	25	26	29	29	28	27	26	24	21	20	19	19	18	16	15	23.2	172.8	7.2
	Nov	23	24	24	22	20	20	20	22	20	18	16	15	14	14	12	10	10	10	9	9	16.6	119.5	5.0
	Dec	23	25	26	26	25	26	27	30	30	30	29	28	27	26	24	22	22	20	19	18	25.2	187.3	7.8

81.8
22.4% Exceed
77.6% Meet

EPA
Moderate
Contract
CI 82%
State Std Dev

E-coli - Percent of Time > 298 MPN/100ml

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Reach Average	Hrs/mo	days/yr
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
Avg 74-78	Jan	14	15	16	15	15	14	16	19	19	18	18	17	16	16	16	15	13	13	13	13	15.7	116.4	4.9
	Feb	14	15	16	16	15	15	16	18	18	17	17	16	16	16	15	15	15	15	14	14	15.5	104.1	4.3
	Mar	19	20	22	21	21	21	23	25	26	24	24	23	23	23	22	21	21	20	19	18	21.8	162.2	6.8
	April	23	23	23	23	22	22	23	24	24	23	23	22	22	21	21	21	20	20	20	18	21.8	157.3	6.6
	May	27	28	30	29	28	29	31	34	34	32	31	31	28	26	24	23	22	21	20	20	27.4	203.6	8.5
	June	26	28	30	29	30	31	33	34	35	35	34	33	32	30	29	28	27	26	25	24	29.9	215.1	9.0
	Jul	29	30	31	30	29	30	32	34	34	32	31	31	29	27	25	23	22	20	18	18	27.8	206.8	8.6
	Aug	37	40	43	42	41	41	42	44	42	41	39	37	35	33	32	30	28	27	26	24	36.1	268.9	11.2
	Sept	22	24	24	24	23	24	27	29	30	29	28	27	25	23	22	20	18	18	17	16	23.4	168.7	7.0
	Oct	24	26	27	27	26	26	27	30	31	30	29	27	26	25	22	20	19	19	18	17	24.8	184.6	7.7
	Nov	25	26	25	24	23	22	22	24	23	21	19	17	17	16	14	12	11	10	10	10	18.6	134.1	5.6
	Dec	24	26	28	28	28	28	30	32	32	32	31	31	30	29	28	26	25	23	22	21	27.7	205.7	8.6

88.6
24.3% Exceed
75.7% Meet

EPA
Moderate
Contract
CI 82%
Local Std Dev

E-coli - Percent of Time > 473 MPN/100ml

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Reach Average	Hrs/mo	days/yr
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
Avg 74-78	Jan	11	12	11	11	10	10	11	13	13	12	11	11	11	11	10	10	9	9	8	9	10.6	79.0	3.3
	Feb	9	10	10	9	9	9	9	10	10	9	8	8	8	8	8	8	7	7	7	7	8.5	56.9	2.4
	Mar	14	15	16	15	15	15	17	18	18	17	16	16	15	15	14	13	12	13	12	12	15.0	111.4	4.6
	April	19	21	20	19	18	18	18	20	19	19	18	18	17	16	15	14	14	13	12	12	17.0	122.2	5.1
	May	19	20	21	21	20	20	20	22	22	20	19	18	16	14	15	15	15	14	14	14	17.9	133.1	5.5
	June	23	24	25	24	25	25	27	29	30	29	27	26	25	23	22	21	21	22	21	21	24.4	175.4	7.3
	Jul	24	25	25	24	23	22	23	25	25	24	23	21	20	19	19	18	16	15	14	12	20.8	154.9	6.5
	Aug	28	30	31	30	28	28	30	32	33	31	29	27	26	24	23	22	21	19	18	16	26.2	194.8	8.1
	Sept	16	17	19	18	17	17	21	24	24	22	20	18	17	15	14	14	13	12	10	9	16.9	121.9	5.1
	Oct	19	20	22	22	20	19	21	23	23	22	19	18	18	17	16	15	15	14	12	11	18.3	136.0	5.7
	Nov	17	16	16	15	14	13	13	15	15	14	13	12	10	8	8	7	6	7	7	7	11.6	83.5	3.5
	Dec	18	19	20	20	20	20	22	24	23	22	21	18	17	17	15	15	15	14	14	14	18.4	137.2	5.7

62.8
17.2% Exceed
82.8% Meet

E-Coli - Monthly Geometric Mean (#/100ml)

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Reach Average	Peak	
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
Avg 74-78	Jan	62	72	76	74	72	72	78	85	86	83	82	80	79	76	73	70	68	65	63	61	73.8	85.5	
	Feb	55	60	62	61	60	60	64	67	67	65	64	63	62	61	59	57	56	54	52	50	60.0	67.1	
	Mar	61	69	73	72	70	73	81	88	89	87	85	83	82	80	77	75	73	70	69	67	76.2	89.2	
	April	92	97	99	97	95	94	99	103	103	100	99	97	96	93	91	89	87	85	83	82	94.1	102.9	
	May	134	148	157	158	154	155	167	179	179	173	166	158	150	141	131	123	115	108	103	99	145.0	179.5	
	June	126	138	145	145	141	142	152	162	164	158	152	145	139	133	125	118	112	106	101	98	135.0	163.6	
	Jul	145	160	165	159	150	149	161	171	169	158	147	137	129	119	108	99	91	85	80	76	132.9	171.1	
	Aug	226	257	270	263	248	243	253	264	258	241	222	205	192	177	163	150	138	130	123	117	207.1	270.2	
	Sept	93	104	108	104	99	103	116	127	128	121	114	109	105	98	91	83	77	74	71	69	99.7	128.4	
	Oct	99	109	112	107	99	96	103	109	106	100	93	87	82	76	69	64	59	55	53	52	86.4	111.7	65 days>126
	Nov	95	103	104	97	90	87	92	97	95	88	81	75	70	64	59	54	50	47	45	44	76.8	103.7	240 Total Days
	Dec	83	100	110	112	110	112	123	133	135	132	129	126	123	119	114	107	102	96	92	88	112.2	135.3	72.9% Compliance

Illness Rate per 1,000 Swimmers based on E-Coli - Monthly Geometric Mean

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Risk Assessment % of Swimmers Average	Peak
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8		
Avg 74-78	Jan	5.1	5.7	5.9	5.8	5.7	5.7	6.1	6.4	6.4	6.3	6.3	6.2	6.1	5.9	5.8	5.6	5.5	5.3	5.2	5.1	0.58%	0.64%
	Feb	4.6	5.0	5.1	5.1	5.0	5.0	5.2	5.4	5.4	5.3	5.3	5.2	5.1	5.0	4.9	4.8	4.7	4.5	4.4	4.3	0.50%	0.54%
	Mar	5.0	5.6	5.8	5.7	5.6	5.8	6.2	6.5	6.6	6.5	6.4	6.3	6.3	6.2	6.0	5.9	5.8	5.6	5.5	5.4	0.59%	0.66%
	April	6.7	6.9	7.0	6.9	6.8	6.8	7.0	7.2	7.2	7.1	7.0	6.9	6.9	6.8	6.7	6.6	6.5	6.4	6.3	6.2	0.68%	0.72%
	May	8.3	8.7	8.9	8.9	8.8	8.9	9.2	9.4	9.5	9.3	9.1	8.9	8.7	8.5	8.2	7.9	7.6	7.4	7.2	7.0	0.85%	0.95%
	June	8.0	8.4	8.6	8.6	8.5	8.5	8.8	9.0	9.1	8.9	8.8	8.6	8.4	8.2	8.0	7.8	7.5	7.3	7.1	7.0	0.82%	0.91%
	Jul	8.6	9.0	9.1	9.0	8.7	8.7	9.0	9.3	9.2	8.9	8.6	8.3	8.1	7.8	7.4	7.0	6.7	6.4	6.2	6.0	0.81%	0.93%
	Aug	10.4	10.9	11.1	11.0	10.8	10.7	10.9	11.0	10.9	10.7	10.3	10.0	9.7	9.4	9.0	8.7	8.4	8.1	7.9	7.7	0.99%	1.11%
	Sept	6.7	7.2	7.4	7.2	7.0	7.2	7.7	8.0	8.1	7.9	7.6	7.4	7.2	7.0	6.7	6.3	6.0	5.8	5.7	5.6	0.70%	0.81%
	Oct	7.0	7.4	7.5	7.3	7.0	6.9	7.2	7.4	7.3	7.1	6.8	6.5	6.3	6.0	5.6	5.2	4.9	4.6	4.5	4.4	0.63%	0.75%
	Nov	6.8	7.2	7.2	7.0	6.6	6.5	6.7	6.9	6.9	6.6	6.2	5.9	5.6	5.3	4.9	4.6	4.2	4.0	3.8	3.7	0.58%	0.72%
	Dec	6.3	7.1	7.4	7.5	7.4	7.5	7.9	8.2	8.3	8.2	8.1	8.0	7.9	7.8	7.6	7.4	7.1	6.9	6.7	6.5	0.75%	0.83%

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City of Richmond, Virginia
Department of Public Utilities
CSO Disinfection Report

James River Water Qualtiy Model Results

Alternative E - SSDF & Shockoe Expand with No Disinfection

Greeley and Hansen LLC
June 2005

State WQS
CI 75%
State Std Dev

E-Coli - Percent of Time > 235 MPN/100ml

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Reach		
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8	Average	Hrs/mo	days/yr
Avg 74-78	Jan	16	18	19	18	18	17	19	22	22	22	22	21	20	19	19	19	18	17	17	17	19.0	141.7	5.9
	Feb	17	19	19	18	17	17	19	21	21	20	19	19	18	18	17	16	16	16	15	15	17.9	120.2	5.0
	Mar	19	22	23	23	23	22	25	28	28	28	27	26	26	25	24	23	22	21	21	20	23.8	177.4	7.4
	April	28	29	29	27	27	27	27	29	29	27	26	25	24	24	23	23	22	21	21	21	25.5	183.3	7.6
	May	31	32	34	34	33	33	36	38	38	37	36	35	34	33	30	28	27	25	25	25	32.2	239.2	10.0
	June	29	31	32	33	32	32	34	36	36	36	36	36	35	35	33	31	30	28	27	26	32.3	232.8	9.7
	Jul	30	32	34	34	32	33	35	39	38	36	34	32	31	30	28	27	25	24	23	20	30.7	228.5	9.5
	Aug	40	43	45	45	43	43	46	48	48	47	44	41	39	38	37	35	34	32	30	27	40.1	298.0	12.4
	Sept	24	27	29	28	27	27	30	31	32	31	30	29	28	25	23	23	22	21	20	20	26.3	189.0	7.9
	Oct	27	29	29	30	28	28	31	33	33	31	31	29	27	26	26	24	21	20	20	19	27.1	201.7	8.4
	Nov	26	27	28	27	26	24	26	29	28	26	24	23	21	20	19	17	16	15	14	12	22.5	161.7	6.7
	Dec	26	28	30	31	30	30	32	35	34	34	33	33	33	33	31	29	28	27	26	26	30.5	227.1	9.5

100.0
27.4% Exceed
72.6% Meet

State WQS
CI 75%
Local Std Dev

E-Coli - Percent of Time >334 MPN/100ml

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
Avg 74-78	Jan	12	13	13	13	12	12	14	17	16	16	16	16	15	14	13	13	13	13	12	12	13.7	101.6	4.2
	Feb	14	14	14	14	14	14	14	16	16	15	15	14	14	14	14	13	13	12	11	10	13.8	92.5	3.9
	Mar	18	19	19	19	19	18	20	22	22	22	20	21	19	19	19	19	17	16	15	14	18.9	140.8	5.9
	April	21	22	22	22	22	22	22	23	23	22	21	21	21	20	20	18	18	17	17	16	20.4	146.8	6.1
	May	23	24	25	25	25	25	27	30	29	28	27	26	24	22	21	20	19	19	18	18	23.7	176.5	7.4
	June	23	25	26	27	27	27	30	32	33	31	30	30	29	28	26	25	25	24	23	22	27.1	195.2	8.1
	Jul	26	27	28	28	27	27	28	31	31	30	30	27	25	24	22	21	19	17	17	15	24.9	185.6	7.7
	Aug	33	36	38	36	34	34	36	38	39	37	36	33	31	28	27	25	25	23	22	21	31.7	235.5	9.8
	Sept	19	20	21	21	20	21	25	27	28	26	25	24	22	21	20	18	17	16	15	14	21.0	151.0	6.3
	Oct	21	22	23	23	23	23	25	28	28	28	27	25	24	21	20	19	19	18	16	15	22.3	166.2	6.9
	Nov	22	22	23	21	19	18	20	22	20	18	16	15	14	14	12	10	10	10	9	9	16.2	116.3	4.8
	Dec	21	23	25	25	24	24	26	29	29	29	28	27	25	23	22	21	20	18	18	17	23.7	176.3	7.3

78.5
21.5% Exceed
78.5% Meet

EPA
Moderate
Contract
CI 82%
State Std Dev

E-coli - Percent of Time > 298 MPN/100ml

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
Avg 74-78	Jan	13	15	15	14	14	14	15	18	19	17	17	17	16	15	16	15	13	13	13	13	15.1	112.4	4.7
	Feb	14	15	15	15	14	14	15	17	17	17	16	15	15	15	15	14	15	14	13	13	14.9	100.4	4.2
	Mar	18	20	21	20	21	20	22	24	25	24	23	22	22	22	21	21	20	19	18	18	20.9	155.8	6.5
	April	22	23	23	22	22	22	23	24	24	23	22	22	22	21	21	20	20	20	20	18	21.7	155.9	6.5
	May	26	28	29	28	27	27	30	32	32	30	30	29	27	24	23	22	21	21	20	19	26.3	195.9	8.2
	June	24	26	28	28	29	29	31	33	34	34	33	32	31	29	28	26	26	25	25	24	28.7	206.4	8.6
	Jul	28	29	31	29	28	29	31	33	33	31	30	29	28	26	23	22	21	19	18	17	26.8	199.5	8.3
	Aug	35	38	40	40	38	38	41	43	41	40	38	36	34	32	30	29	26	25	24	23	34.5	256.7	10.7
	Sept	22	23	23	23	22	22	26	28	29	28	26	26	23	23	22	20	18	18	17	16	22.7	163.6	6.8
	Oct	23	24	25	25	23	24	26	29	30	29	28	27	26	24	22	20	19	18	18	17	23.9	177.6	7.4
	Nov	24	25	24	23	22	21	22	24	23	21	19	17	17	16	14	12	11	10	10	10	18.2	131.4	5.5
	Dec	23	24	26	27	26	27	29	31	31	30	30	29	28	26	25	25	24	22	21	20	26.1	194.2	8.1

85.4
23.4% Exceed
76.6% Meet

EPA
Moderate
Contract
CI 82%
Local Std Dev

E-coli - Percent of Time > 473 MPN/100ml

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
Avg 74-78	Jan	10	11	10	10	9	9	10	12	12	11	11	10	11	10	9	10	9	8	8	9	9.9	74.0	3.1
	Feb	9	9	9	9	8	8	8	10	9	9	8	8	8	8	7	7	7	7	7	7	8.1	54.7	2.3
	Mar	14	15	15	15	15	15	16	18	18	16	16	15	15	14	13	12	12	12	12	11	14.4	106.9	4.5
	April	19	20	20	19	18	18	18	20	19	19	18	17	16	16	14	14	13	12	12	12	16.7	120.4	5.0
	May	18	19	20	20	19	19	19	20	20	20	18	17	15	14	14	14	14	14	14	14	17.1	127.2	5.3
	June	22	23	24	23	23	23	24	27	28	27	26	25	23	22	21	21	21	21	21	21	23.2	167.2	7.0
	Jul	23	24	24	22	22	21	22	24	24	22	22	20	20	18	18	16	15	12	12	12	19.6	145.7	6.1
	Aug	26	28	28	27	27	26	27	31	31	29	27	25	25	23	22	21	20	18	18	16	24.7	183.7	7.7
	Sept	15	16	18	18	17	17	20	23	23	21	20	17	16	15	14	14	13	12	10	9	16.4	118.4	4.9
	Oct	18	19	20	20	19	19	20	22	22	21	18	18	17	16	16	15	15	14	12	11	17.5	129.8	5.4
	Nov	16	16	15	14	14	13	13	15	14	14	13	12	10	8	8	7	6	7	7	7	11.3	81.5	3.4
	Dec	17	17	18	18	18	17	19	21	21	20	18	17	16	15	15	14	14	14	13	13	16.8	124.8	5.2

59.8
16.4% Exceed
83.6% Meet

E-Coli - Monthly Geometric Mean (#/100ml)

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Reach		
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8	Average	Peak	
Avg 74-78	Jan	60	70	74	72	70	70	77	83	84	82	81	79	77	74	71	68	66	63	61	60	72.1	84.0	
	Feb	54	59	61	60	59	59	63	66	66	64	63	62	61	59	58	56	54	52	51	49	58.7	65.9	
	Mar	59	67	71	70	68	70	78	84	86	84	82	80	79	78	75	72	70	68	66	64	73.5	85.9	
	April	91	95	97	96	93	93	98	102	102	99	98	96	95	92	90	88	86	84	83	81	92.9	101.6	
	May	128	142	151	151	147	149	161	173	174	168	161	153	146	138	129	120	113	106	102	97	140.4	173.6	
	June	120	131	138	138	134	135	145	155	157	151	145	139	134	127	120	114	108	102	98	95	129.5	156.7	
	Jul	136	151	156	151	143	142	154	165	163	152	141	131	123	113	103	94	86	80	75	71	126.6	164.7	
	Aug	203	232	245	239	225	222	235	247	244	228	211	195	183	169	154	142	131	123	118	112	192.8	247.1	
	Sept	87	98	102	99	95	99	112	124	125	119	112	107	103	96	89	82	76	72	70	68	96.7	125.5	
	Oct	93	104	107	102	95	92	99	105	103	97	90	84	80	74	67	62	57	53	51	50	83.2	106.6	59 days>126
	Nov	89	98	99	94	87	85	90	96	94	87	80	74	69	64	59	54	50	47	45	43	75.2	99.4	240 Total Days
	Dec	78	94	104	105	104	106	116	127	128	125	122	119	117	113	107	101	96	90	86	83	106.1	128.4	75.4% Compliance

Illness Rate per 1,000 Swimmers based on E-Coli - Monthly Geometric Mean

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Risk Assessment % of Swimmers	
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8	Average	Peak
Avg 74-78	Jan	5.0	5.6	5.8	5.7	5.6	5.6	6.0	6.3	6.4	6.3	6.2	6.1	6.0	5.9	5.7	5.5	5.4	5.2	5.1	4.9	0.57%	0.64%
	Feb	4.5	4.9	5.0	5.0	4.9	4.9	5.2	5.4	5.4	5.3	5.2	5.1	5.0	4.9	4.8	4.7	4.6	4.4	4.3	4.2	0.49%	0.54%
	Mar	4.9	5.4	5.6	5.6	5.5	5.6	6.0	6.4	6.4	6.3	6.2	6.2	6.1	6.0	5.9	5.7	5.6	5.5	5.4	5.3	0.58%	0.64%
	April	6.7	6.9	7.0	6.9	6.8	6.8	7.0	7.1	7.1	7.0	7.0	6.9	6.8	6.7	6.6	6.6	6.5	6.4	6.3	6.2	0.68%	0.71%
	May	8.1	8.5	8.7	8.7	8.6	8.7	9.0	9.3	9.3	9.2	9.0	8.8	8.6	8.4	8.1	7.8	7.6	7.3	7.1	7.0	0.84%	0.93%
	June	7.8	8.2	8.4	8.4	8.3	8.3	8.6	8.9	8.9	8.8	8.6	8.4	8.3	8.1	7.8	7.6	7.4	7.2	7.0	6.8	0.81%	0.89%
	Jul	8.3	8.7	8.9	8.8	8.5	8.5	8.8	9.1	9.1	8.8	8.5	8.2	7.9	7.6	7.2	6.8	6.4	6.1	5.9	5.7	0.79%	0.91%
	Aug	10.0	10.5	10.7	10.6	10.4	10.3	10.6	10.8	10.7	10.4	10.1	9.8	9.5	9.2	8.8	8.5	8.2	7.9	7.7	7.5	0.96%	1.08%
	Sept	6.5	7.0	7.2	7.0	6.9	7.0	7.5	7.9	8.0	7.8	7.5	7.3	7.2	6.9	6.6	6.2	5.9	5.7	5.6	5.5	0.69%	0.80%
	Oct	6.8	7.2	7.3	7.1	6.8	6.7	7.0	7.3	7.2	6.9	6.6	6.3	6.1	5.8	5.4	5.1	4.8	4.5	4.3	4.2	0.62%	0.73%
	Nov	6.6	7.0	7.0	6.8	6.5	6.4	6.6	6.9	6.8	6.5	6.2	5.9	5.6	5.2	4.9	4.5	4.2	4.0	3.8	3.6	0.57%	0.70%
	Dec	6.1	6.8	7.2	7.3	7.2	7.3	7.7	8.0	8.1	8.0	7.9	7.8	7.7	7.6	7.3	7.1	6.9	6.7	6.5	6.3	0.73%	0.81%

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CSO Disinfection Report

James River Water Qualtiy Model Results

Alternative E - SSDF & Shockoe Expand with 4,000 UV Lamps

Greeley and Hansen LLC
June 2005

State WQS
CI 75%
State Std Dev

E-Coli - Percent of Time > 235 MPN/100ml

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Reach		
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8	Average	Hrs/mo	days/yr
Avg 74-78	Jan	15	17	19	18	17	17	19	21	22	22	22	20	19	18	18	18	17	17	16	16	18.4	136.7	5.7
	Feb	17	19	19	18	17	17	19	21	21	19	19	19	18	18	17	16	16	16	15	15	17.7	119.2	5.0
	Mar	18	21	22	22	22	21	24	27	28	27	26	25	25	24	23	22	21	20	19	19	22.8	169.3	7.1
	April	27	28	29	27	26	26	26	28	28	26	26	24	23	23	22	22	21	20	20	19	24.7	177.7	7.4
	May	31	31	33	33	33	33	35	38	38	36	35	35	33	32	29	27	26	25	25	25	31.7	236.2	9.8
	June	28	30	31	31	32	31	33	35	36	36	35	35	35	33	31	30	29	27	26	25	31.4	226.3	9.4
	Jul	28	31	32	32	31	31	34	37	36	35	32	31	29	28	27	24	22	21	20	19	28.9	215.3	9.0
	Aug	38	42	44	43	41	42	45	46	47	46	43	40	38	35	34	32	31	29	27	24	38.4	285.4	11.9
	Sept	22	25	27	26	24	25	27	28	29	28	27	26	25	22	21	21	19	18	18	16	23.7	170.4	7.1
	Oct	25	27	27	28	26	27	29	32	31	30	30	27	26	25	25	23	20	19	18	17	25.6	190.7	7.9
	Nov	26	26	27	26	25	24	25	28	27	25	23	22	21	19	18	17	16	14	12	12	21.7	156.3	6.5
	Dec	23	26	28	29	28	28	30	33	32	32	31	30	30	29	27	25	24	23	22	22	27.7	206.0	8.6

95.4
26.1% Exceed
73.9% Meet

State WQS
CI 75%
Local Std Dev

E-Coli - Percent of Time >334 MPN/100ml

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
Avg 74-78	Jan	11	12	13	12	12	11	13	16	16	15	15	14	13	13	12	11	11	11	11	10	12.6	93.8	3.9
	Feb	14	14	14	14	14	13	14	15	15	15	15	14	14	14	13	13	13	12	11	10	13.6	91.3	3.8
	Mar	17	18	18	18	18	17	18	21	21	20	19	19	18	17	17	17	15	14	13	13	17.4	129.6	5.4
	April	20	21	22	21	21	21	21	22	22	21	20	20	20	19	18	17	17	15	15	15	19.4	139.8	5.8
	May	23	24	24	24	24	24	26	29	28	28	27	25	23	21	20	19	18	18	18	17	22.9	170.4	7.1
	June	22	24	26	26	26	26	29	31	32	31	30	29	28	26	25	24	22	22	22	21	25.9	186.7	7.8
	Jul	24	26	27	26	24	24	27	29	28	27	27	24	22	20	17	16	15	13	12	12	22.0	163.6	6.8
	Aug	30	34	36	35	32	32	35	37	38	35	33	30	29	27	26	24	23	21	20	19	29.7	220.9	9.2
	Sept	17	18	19	19	18	18	22	24	25	24	23	22	20	19	17	15	14	13	11	11	18.5	133.1	5.5
	Oct	19	20	21	21	21	21	24	26	26	26	25	23	21	18	18	17	15	15	14	13	20.3	151.0	6.3
	Nov	22	22	22	20	18	17	19	21	19	18	15	14	13	13	10	10	9	9	9	9	15.4	111.2	4.6
	Dec	19	21	22	22	21	21	24	26	27	26	24	23	21	20	18	17	16	14	13	12	20.3	151.2	6.3

72.6
19.9% Exceed
80.1% Meet

EPA
Moderate
Contract
CI 82%
State Std Dev

E-coli - Percent of Time > 298 MPN/100ml

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
Avg 74-78	Jan	11	14	14	13	13	13	15	18	18	17	16	16	15	15	15	14	12	12	12	12	14.2	105.8	4.4
	Feb	14	15	15	15	14	14	15	17	17	16	16	15	15	15	14	14	14	14	13	13	14.7	99.0	4.1
	Mar	17	19	20	19	19	19	21	23	23	22	21	21	20	20	19	19	18	18	16	16	19.6	145.5	6.1
	April	21	22	22	22	22	21	22	23	23	22	22	21	21	20	20	19	19	18	18	16	20.7	149.2	6.2
	May	26	27	28	27	27	27	29	32	31	30	30	29	26	23	22	21	21	21	20	19	25.8	191.6	8.0
	June	23	25	27	27	28	28	30	32	33	33	32	31	30	28	26	25	24	24	23	23	27.6	198.8	8.3
	Jul	26	28	29	27	26	27	29	31	31	29	28	27	26	24	20	18	18	15	15	13	24.3	181.0	7.5
	Aug	32	36	39	38	37	36	39	42	40	39	36	33	31	30	28	27	24	23	22	20	32.6	242.6	10.1
	Sept	20	21	21	21	19	19	24	25	27	25	24	23	21	20	19	18	15	15	14	12	20.3	145.8	6.1
	Oct	21	22	23	23	22	22	25	28	28	28	27	26	25	23	19	18	17	16	15	15	22.1	164.6	6.9
	Nov	23	24	24	23	21	20	21	23	22	20	18	16	16	15	13	11	10	10	10	9	17.4	125.5	5.2
	Dec	20	22	24	25	24	24	27	29	29	28	27	26	24	23	21	20	19	17	16	15	23.0	170.8	7.1

80.0
21.9% Exceed
78.1% Meet

EPA
Moderate
Contract
CI 82%
Local Std Dev

E-coli - Percent of Time > 473 MPN/100ml

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
Avg 74-78	Jan	9	9	9	9	8	8	9	11	11	10	9	9	9	9	8	7	7	6	6	6	8.4	62.8	2.6
	Feb	9	9	9	9	8	8	8	9	9	8	8	7	7	8	7	7	7	7	7	7	8.0	53.7	2.2
	Mar	12	13	13	13	13	13	15	16	16	14	14	13	12	12	11	11	11	11	10	10	12.7	94.4	3.9
	April	18	19	19	18	17	17	17	18	18	17	17	16	15	14	13	12	12	11	11	11	15.5	111.4	4.6
	May	18	19	19	19	17	17	17	20	20	19	18	16	15	14	14	14	13	13	12	12	16.2	120.9	5.0
	June	21	22	22	22	22	22	23	26	27	26	24	23	22	21	20	20	19	19	18	18	21.9	157.6	6.6
	Jul	20	21	22	20	19	17	19	22	22	20	19	17	14	12	12	12	10	9	9	8	16.2	120.9	5.0
	Aug	23	25	25	25	24	23	25	28	28	27	25	23	22	21	20	18	18	16	15	12	22.2	165.2	6.9
	Sept	13	14	15	15	14	14	18	21	21	18	16	15	13	13	12	10	10	9	8	7	13.8	99.5	4.1
	Oct	16	17	18	18	17	16	18	20	20	18	16	15	14	14	12	12	12	12	11	9	15.2	113.0	4.7
	Nov	15	15	14	13	13	12	12	14	14	13	12	11	9	8	7	7	6	6	6	6	10.7	77.0	3.2
	Dec	15	15	15	15	15	14	16	18	17	16	15	13	12	12	10	10	10	9	9	9	13.3	98.6	4.1

53.1
14.6% Exceed
85.4% Meet

E-Coli - Monthly Geometric Mean (#/100ml)

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Reach		
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8	Average	Peak	
Avg 74-78	Jan	56	65	69	68	65	66	72	79	79	77	76	74	73	70	67	64	62	59	57	56	67.8	79.5	
	Feb	54	58	60	60	58	59	62	66	66	64	63	62	61	59	57	56	54	52	50	49	58.4	65.7	
	Mar	56	63	67	66	64	66	74	80	82	80	78	77	76	74	72	70	68	65	64	62	70.1	81.8	
	April	86	91	93	92	89	89	93	97	97	95	93	92	91	88	86	85	83	80	79	77	88.8	97.3	
	May	125	138	146	146	143	145	156	168	169	163	157	150	143	134	126	118	111	104	99	95	136.8	169.0	
	June	115	125	131	131	127	128	138	148	149	144	138	132	127	121	114	108	102	96	92	88	122.7	149.3	
	Jul	115	127	133	129	121	121	134	144	143	134	124	115	107	99	89	81	74	69	65	62	109.3	144.3	
	Aug	176	201	213	208	196	194	206	218	215	202	187	173	162	150	137	126	116	109	103	98	169.5	217.9	
	Sept	74	82	86	83	79	82	93	102	103	97	91	85	82	77	71	65	61	58	57	55	79.1	102.6	
	Oct	79	88	91	88	82	80	86	93	91	86	80	75	71	66	60	55	50	47	46	45	72.9	92.8	46 days>126
	Nov	84	92	94	89	83	81	87	92	91	85	78	72	67	62	57	52	48	45	43	42	72.1	94.3	240 Total Days
	Dec	71	85	94	95	93	95	105	114	116	113	110	107	105	101	96	91	86	81	77	74	95.5	115.9	80.8% Compliance

Illness Rate per 1,000 Swimmers based on E-Coli - Monthly Geometric Mean

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Risk Assessment % of Swimmers	
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8	Average	Peak
Avg 74-78	Jan	4.7	5.3	5.5	5.5	5.3	5.4	5.7	6.1	6.1	6.0	5.9	5.8	5.8	5.6	5.4	5.3	5.1	4.9	4.8	4.7	0.54%	0.61%
	Feb	4.5	4.9	5.0	5.0	4.9	4.9	5.1	5.3	5.3	5.2	5.2	5.1	5.0	4.9	4.8	4.7	4.5	4.4	4.3	4.1	0.49%	0.53%
	Mar	4.7	5.2	5.4	5.4	5.2	5.4	5.8	6.2	6.2	6.1	6.1	6.0	5.9	5.9	5.7	5.6	5.5	5.3	5.2	5.1	0.56%	0.62%
	April	6.5	6.7	6.8	6.7	6.6	6.6	6.8	7.0	7.0	6.9	6.8	6.7	6.7	6.6	6.5	6.4	6.3	6.2	6.1	6.0	0.66%	0.70%
	May	8.0	8.4	8.6	8.6	8.5	8.6	8.9	9.2	9.2	9.1	8.9	8.7	8.5	8.3	8.0	7.7	7.5	7.2	7.0	6.9	0.83%	0.92%
	June	7.6	8.0	8.2	8.2	8.0	8.1	8.4	8.7	8.7	8.6	8.4	8.2	8.0	7.8	7.6	7.4	7.1	6.9	6.7	6.6	0.78%	0.87%
	Jul	7.6	8.1	8.2	8.1	7.8	7.8	8.2	8.6	8.5	8.3	7.9	7.6	7.4	7.0	6.6	6.2	5.8	5.5	5.3	5.1	0.73%	0.86%
	Aug	9.4	9.9	10.1	10.0	9.8	9.8	10.0	10.2	10.2	9.9	9.6	9.3	9.0	8.7	8.4	8.0	7.7	7.4	7.2	7.0	0.91%	1.02%
	Sept	5.8	6.3	6.5	6.3	6.1	6.2	6.8	7.2	7.2	6.9	6.7	6.4	6.3	6.0	5.7	5.3	5.0	4.8	4.7	4.6	0.60%	0.72%
	Oct	6.1	6.5	6.7	6.5	6.2	6.2	6.5	6.8	6.7	6.4	6.2	5.9	5.7	5.4	5.0	4.6	4.3	4.0	3.9	3.8	0.57%	0.68%
	Nov	6.4	6.7	6.8	6.6	6.3	6.2	6.5	6.7	6.7	6.4	6.0	5.7	5.4	5.1	4.7	4.4	4.1	3.8	3.6	3.5	0.56%	0.68%
	Dec	5.7	6.4	6.8	6.8	6.8	6.8	7.3	7.6	7.7	7.6	7.5	7.3	7.3	7.1	6.9	6.7	6.4	6.2	6.0	5.8	0.68%	0.77%

City of Richmond, Virginia
Department of Public Utilities
CSO Disinfection Report

James River Water Qualtiy Model Results

Alternative E - SSDF & Shockoe Expand with 8,000 UV Lamps

Greeley and Hansen LLC
June 2005

State WQS
CI 75%
State Std Dev

E-Coli - Percent of Time > 235 MPN/100ml																						Reach		
Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Average	Hrs/mo	days/yr
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
Avg 74-78	Jan	15	17	19	18	17	17	19	21	22	22	22	20	19	18	18	18	17	17	16	16	18.4	136.6	5.7
	Feb	17	19	19	18	17	17	19	21	21	19	19	19	18	18	17	16	16	16	15	15	17.7	119.2	5.0
	Mar	18	21	22	22	22	21	24	27	28	27	26	25	25	24	23	22	21	20	19	19	22.8	169.3	7.1
	April	27	28	29	27	26	26	26	28	28	26	26	24	23	23	22	22	21	20	20	19	24.7	177.6	7.4
	May	31	31	33	33	33	33	35	38	38	36	35	34	33	32	29	27	26	25	25	25	31.7	235.7	9.8
	June	28	30	31	31	32	31	33	35	36	35	35	35	34	33	31	30	29	27	26	25	31.3	225.7	9.4
	Jul	28	31	32	32	30	31	34	37	36	34	32	31	29	28	27	23	21	20	19	18	28.6	212.7	8.9
	Aug	38	42	44	43	41	41	44	46	46	45	42	40	37	35	33	31	30	28	26	23	37.9	282.0	11.8
	Sept	22	25	26	26	24	24	26	28	29	28	26	25	25	22	21	20	19	18	18	16	23.5	168.9	7.0
	Oct	25	26	27	28	26	27	29	32	31	30	29	27	26	25	24	23	20	19	18	17	25.5	189.9	7.9
	Nov	26	26	27	26	25	24	25	28	27	25	23	22	21	19	18	17	16	14	12	12	21.7	156.1	6.5
	Dec	23	26	28	29	28	28	30	33	32	32	31	30	30	29	27	25	24	23	22	22	27.6	205.5	8.6

95.0
26.0% Exceed
74.0% Meet

State WQS
CI 75%
Local Std Dev

E-Coli - Percent of Time >334 MPN/100ml																								
Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
Avg 74-78	Jan	11	12	13	12	12	11	13	16	16	15	15	14	13	13	12	11	11	11	11	10	12.6	93.7	3.9
	Feb	14	14	14	14	14	13	14	15	15	15	15	14	14	14	13	13	13	12	11	10	13.6	91.3	3.8
	Mar	17	18	18	18	18	17	18	21	21	20	19	19	18	17	17	17	15	14	13	13	17.4	129.6	5.4
	April	20	21	22	21	21	21	21	22	22	21	20	20	20	19	18	17	17	15	15	15	19.4	139.6	5.8
	May	23	24	24	24	24	24	26	29	28	28	27	25	23	21	20	18	18	18	17	16	22.7	169.1	7.0
	June	22	24	26	26	26	26	29	31	32	30	30	29	28	26	25	24	22	21	21	20	25.8	186.0	7.7
	Jul	24	25	26	25	24	24	26	28	28	27	26	24	22	19	17	15	14	13	12	12	21.6	160.4	6.7
	Aug	30	33	36	35	32	32	34	37	37	34	32	29	28	26	25	23	22	20	19	18	29.0	215.6	9.0
	Sept	17	17	19	19	18	18	22	24	25	24	23	22	20	19	16	15	14	13	11	11	18.3	132.1	5.5
	Oct	19	20	21	21	21	21	24	26	26	26	25	23	21	18	18	17	15	15	14	13	20.2	150.2	6.3
	Nov	22	22	22	20	18	17	19	21	19	18	15	14	13	13	10	10	9	9	9	8	15.4	111.1	4.6
	Dec	19	21	22	22	21	21	24	26	27	26	24	23	21	19	18	17	16	14	13	12	20.3	150.8	6.3

72.1
19.7% Exceed
80.3% Meet

EPA
Moderate
Contract
CI 82%
State Std Dev

E-coli - Percent of Time > 298 MPN/100ml																								
Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
Avg 74-78	Jan	11	14	14	13	13	13	15	18	18	17	16	16	15	15	15	14	12	12	12	11	14.2	105.4	4.4
	Feb	14	15	15	15	14	14	15	17	17	16	16	15	15	15	14	14	14	14	13	13	14.7	99.0	4.1
	Mar	17	19	20	19	19	19	21	23	23	22	21	21	20	20	19	19	18	18	16	16	19.5	145.4	6.1
	April	21	22	22	22	22	21	22	23	23	22	22	21	21	20	20	19	19	18	18	16	20.7	149.2	6.2
	May	26	27	28	27	26	27	29	32	31	30	30	29	26	23	22	21	21	20	19	18	25.7	190.9	8.0
	June	23	25	27	27	28	28	30	32	33	33	32	31	30	27	26	25	24	23	23	22	27.5	198.2	8.3
	Jul	26	28	29	27	25	26	29	31	30	28	27	27	26	23	19	18	17	15	14	13	24.0	178.2	7.4
	Aug	32	36	38	38	37	36	39	41	39	38	35	32	30	29	27	26	23	22	21	19	31.9	237.6	9.9
	Sept	19	21	21	21	19	19	23	25	27	25	24	23	21	20	19	18	15	15	14	12	20.1	145.0	6.0
	Oct	21	22	23	23	22	22	24	28	28	28	26	25	25	23	19	18	17	16	15	15	22.0	163.6	6.8
	Nov	23	24	24	23	21	20	21	23	22	20	18	16	16	15	13	11	10	10	10	9	17.4	125.2	5.2
	Dec	20	22	24	25	24	24	27	29	28	28	27	26	24	23	21	20	19	17	16	15	22.9	170.6	7.1

79.5
21.8% Exceed
78.2% Meet

EPA
Moderate
Contract
CI 82%
Local Std Dev

E-coli - Percent of Time > 473 MPN/100ml																								
Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
Avg 74-78	Jan	8	9	9	9	8	8	9	11	11	10	9	9	9	9	8	7	7	6	6	6	8.4	62.5	2.6
	Feb	9	9	9	9	8	8	8	9	9	8	8	7	7	8	7	7	7	7	7	7	8.0	53.7	2.2
	Mar	12	13	13	13	13	13	15	16	16	14	14	13	12	12	11	11	11	11	10	10	12.7	94.4	3.9
	April	18	19	19	18	17	17	17	18	18	17	17	16	15	14	13	12	12	11	11	11	15.4	111.2	4.6
	May	18	19	19	19	17	17	17	20	20	19	18	16	15	14	14	13	13	12	12	12	16.2	120.4	5.0
	June	21	22	22	22	22	22	23	26	27	26	24	23	21	21	20	19	19	19	18	17	21.7	156.3	6.5
	Jul	19	21	21	19	18	17	19	22	22	20	19	15	13	12	12	11	10	9	8	8	15.8	117.6	4.9
	Aug	23	24	25	24	24	23	25	28	28	27	25	23	22	20	19	17	17	15	12	12	21.5	160.1	6.7
	Sept	13	14	15	15	14	14	18	21	21	18	16	14	13	12	11	10	10	9	8	7	13.6	97.8	4.1
	Oct	16	17	18	18	17	16	18	19	20	18	16	15	14	13	12	12	12	11	10	9	15.0	111.6	4.7
	Nov	15	15	14	13	13	12	12	14	14	13	12	11	9	8	7	7	6	6	6	6	10.7	77.0	3.2
	Dec	15	15	15	15	15	14	16	18	17	16	15	13	12	12	10	10	10	9	9	9	13.2	98.4	4.1

52.5
14.4% Exceed
85.6% Meet

E-Coli - Monthly Geometric Mean (#/100ml)																						Reach	
Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Average	Peak
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8		
Avg 74-78	Jan	56	65	69	67	65	66	72	78	79	77	76	74	73	70	67	64	62	59	57	56	67.6	79.3
	Feb	54	58	60	60	58	59	62	66	66	64	63	62	61	59	57	56	54	52	50	49	58.4	65.7
	Mar	56	63	67	66	64	66	74	80	82	80	78	77	76	74	72	70	68	65	64	62	70.1	81.7
	April	86	91	93	91	89	89	93	97	97	95	93	92	91	88	86	84	82	80	79	77	88.7	97.2
	May	125	138	146	146	143	144	156	167	168	163	156	149	142	134	125	118	110	104	99	95	136.4	168.4
	June	115	124	131	130	127	128	138	148	149	144	138	131	126	120	113	107	101	95	91	88	122.2	148.9
	Jul	112	124	129	125	117	118	130	141	140	131	121	112	105	96	87	79	72	67	64	60	106.6	140.9
	Aug	169	192	203	198	187	185	196	208	205	193	178	164	154	142	130	120	110	103	98	93	161.5	207.8
	Sept	73	82	85	82	78	81	92	101	101	95	89	84	80	75	69	64	59	56	55	53	77.8	101.3
	Oct	78	87	90	86	80	79	85	92	90	85	79	74	70	65	59	54	50	47	45	44	72.0	91.7
	Nov	84	92	94	89	83	81	87	92	91	84	78	72	67	62	56	52	48	45	43	41	72.0	94.2
	Dec	71	85	93	95	93	95	105	114	116	113	110	107	105	101	96	91	86	81	77	74	95.4	115.8

44 days>126
240 Total Days
81.7% Compliance

Illness Rate per 1,000 Swimmers based on E-Coli - Monthly Geometric Mean																						Risk Assessment % of Swimmers	
Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Average	Peak
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8		
Avg 74-78	Jan	4.7	5.3	5.5	5.5	5.3	5.3	5.7	6.1	6.1	6.0	5.9	5.8	5.8	5.6	5.4	5.3	5.1	4.9	4.8	4.7	0.54%	0.61%
	Feb	4.5	4.9	5.0	5.0	4.9	4.9	5.1	5.3	5.3	5.2	5.2	5.1	5.0	4.9	4.8	4.7	4.5	4.4	4.3	4.1	0.49%	0.53%
	Mar	4.7	5.2	5.4	5.4	5.2	5.4	5.8	6.2	6.2	6.1	6.1	6.0	5.9	5.9	5.7	5.6	5.5	5.3	5.2	5.1	0.56%	0.62%
	April	6.4	6.7	6.8	6.7	6.6	6.6	6.8	6.9	6.9	6.9	6.8	6.7	6.7	6.6	6.5	6.4	6.3	6.2	6.1	6.0	0.66%	0.69%
	May	8.0	8.4	8.6	8.6	8.5	8.6	8.9	9.2	9.2	9.0	8.9	8.7	8.5	8.3	8.0	7.7	7.5	7.2	7.0	6.8	0.83%	0.92%
	June	7.6	8.0	8.2	8.1	8.0	8.1	8.4	8.7	8.7	8.5	8.4	8.2	8.0	7.8	7.6	7.3	7.1	6.9	6.7	6.5	0.78%	0.87%
	Jul	7.5	7.9	8.1	8.0	7.7	7.7	8.1	8.5	8.4	8.2	7.9	7.5	7.3	6.9	6.5	6.1	5.7	5.4	5.2	5.0	0.72%	0.85%
	Aug	9.2	9.7	10.0	9.9	9.6	9.6	9.8	10.0	10.0	9.7	9.4	9.1	8.8	8.5	8.1	7.8	7.5	7.2	7.0	6.8	0.89%	1.00%
	Sept	5.8	6.2	6.4	6.3	6.1	6.2	6.7	7.1	7.1	6.9	6.6	6.3	6.2	5.9	5.6	5.2	4.9	4.7	4.6	4.5	0.60%	0.71%
	Oct	6.1	6.5	6.6	6.5	6.2	6.1	6.4	6.7	6.6	6.4	6.1	5.8	5.6	5.3	4.9	4.6	4.2	4.0	3.8	3.7	0.56%	0.67%
	Nov	6.4	6.7	6.8	6.6	6.3	6.2	6.5	6.7	6.7	6.4	6.0	5.7	5.4	5.1	4.7	4.4	4.0	3.8	3.6	3.5	0.56%	0.68%
	Dec	5.7	6.4	6.8	6.8	6.8	6.8	7.2	7.6	7.7	7.6	7.4	7.3	7.3	7.1	6.9	6.7	6.4	6.2	6.0	5.8	0.68%	0.77%

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City of Richmond, Virginia
Department of Public Utilities
CSO Disinfection Report

James River Water Quality Model Results

Alternative E - SSDF & Shockoe Expand with 12,000 UV Lamps

Greeley and Hansen LLC
June 2005

E-Coli - Percent of Time > 235 MPN/100ml

	Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Reach		
			98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8	Average	Hrs/mo	days/yr
State WQS	Avg	Jan	15	17	19	18	17	17	19	21	22	22	22	20	19	18	18	18	17	17	16	16	18.4	136.6	5.7
CI 75%	74-78	Feb	17	19	19	18	17	17	19	21	21	19	19	19	18	18	17	16	16	16	15	15	17.7	119.2	5.0
State Std Dev		Mar	18	21	22	22	22	21	24	27	28	27	26	25	25	24	23	22	21	20	19	19	22.8	169.3	7.1
		April	27	28	29	27	26	26	26	28	28	26	26	24	23	23	22	22	21	20	20	19	24.7	177.6	7.4
		May	31	31	33	33	33	33	35	38	38	36	35	34	33	32	29	27	26	25	25	25	31.7	235.6	9.8
		June	28	30	31	31	32	31	33	35	36	35	35	35	34	33	31	30	29	27	26	25	31.3	225.5	9.4
		Jul	28	30	32	32	30	30	34	37	35	34	32	30	29	27	26	23	21	20	19	18	28.5	211.8	8.8
		Aug	38	41	44	43	41	41	44	46	46	45	42	39	37	35	33	31	30	28	25	22	37.5	279.2	11.6
		Sept	22	25	26	26	24	24	26	28	29	28	26	25	25	22	21	20	19	18	18	16	23.5	168.9	7.0
		Oct	25	26	27	28	26	27	29	32	31	30	29	27	26	25	24	23	20	19	18	17	25.5	189.7	7.9
		Nov	26	26	27	26	25	24	25	28	27	25	23	22	21	19	18	17	16	14	12	12	21.7	156.1	6.5
		Dec	23	26	28	29	28	28	30	33	32	32	31	30	30	29	27	25	24	23	22	22	27.6	205.5	8.6

94.8
26.0% Exceed
74.0% Meet

E-Coli - Percent of Time >334 MPN/100ml

	Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
			98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
State WQS	Avg	Jan	11	12	13	12	12	11	13	16	16	15	15	14	13	13	12	11	11	11	11	10	12.6	93.6	3.9
CI 75%	74-78	Feb	14	14	14	14	14	13	14	15	15	15	15	14	14	14	13	13	13	12	11	10	13.6	91.3	3.8
Local Std Dev		Mar	17	18	18	18	18	17	18	21	21	20	19	19	18	17	17	17	15	14	13	13	17.4	129.6	5.4
		April	20	21	22	21	21	21	21	22	22	21	20	20	20	19	18	17	17	15	15	15	19.4	139.6	5.8
		May	23	24	24	24	24	24	26	29	28	28	26	25	23	21	20	18	18	17	17	16	22.7	168.9	7.0
		June	22	24	25	26	26	26	29	31	32	30	30	29	28	26	25	24	22	21	21	20	25.8	185.6	7.7
		Jul	24	25	26	25	24	24	26	28	28	27	26	24	22	19	16	15	14	12	12	12	21.4	159.5	6.6
		Aug	30	33	35	34	32	32	34	37	37	34	31	29	27	25	24	22	21	19	18	16	28.6	212.7	8.9
		Sept	17	17	19	19	18	18	22	24	25	24	23	22	20	19	16	15	14	13	11	11	18.3	131.9	5.5
		Oct	19	20	21	21	21	21	24	26	26	26	25	23	21	18	18	17	15	15	14	13	20.2	150.0	6.3
		Nov	22	22	22	20	18	17	19	21	19	18	15	14	13	13	10	10	9	9	9	8	15.4	111.1	4.6
		Dec	19	21	22	22	21	21	24	26	27	26	24	23	21	19	18	17	16	14	13	12	20.3	150.8	6.3

71.9
19.7% Exceed
80.3% Meet

E-coli - Percent of Time > 298 MPN/100ml

	Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
			98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
EPA	Avg	Jan	11	14	14	13	13	13	15	18	18	17	16	16	15	15	15	14	12	12	12	11	14.2	105.4	4.4
Moderate	74-78	Feb	14	15	15	15	14	14	15	17	17	16	16	15	15	15	14	14	14	14	13	13	14.7	99.0	4.1
Contract		Mar	17	19	20	19	19	19	21	23	23	22	21	21	20	20	19	19	18	18	16	16	19.5	145.4	6.1
CI 82%		April	21	22	22	22	22	21	22	23	23	22	22	21	21	20	20	19	19	18	18	16	20.7	149.2	6.2
State Std Dev		May	26	27	28	27	26	27	29	32	31	30	30	29	26	23	22	21	21	20	19	18	25.6	190.7	7.9
		June	23	25	27	27	28	28	30	32	33	33	32	31	30	27	26	25	24	23	23	22	27.5	197.9	8.2
		Jul	26	28	29	27	25	26	29	31	30	28	27	27	25	23	19	18	17	15	14	13	23.9	177.5	7.4
		Aug	32	35	38	38	37	36	39	41	39	38	35	32	30	28	27	25	23	21	20	18	31.5	234.6	9.8
		Sept	19	21	21	21	19	19	23	25	27	25	24	23	21	20	19	17	15	15	14	12	20.1	144.6	6.0
		Oct	21	22	23	23	22	22	24	28	28	28	26	25	24	23	19	18	17	16	15	15	21.9	163.2	6.8
		Nov	23	24	24	23	21	20	21	23	22	20	18	16	16	15	13	11	10	10	10	9	17.4	125.2	5.2
		Dec	20	22	24	25	24	24	27	29	28	28	27	26	24	23	21	20	19	17	16	15	22.9	170.6	7.1

79.3
21.7% Exceed
78.3% Meet

E-coli - Percent of Time > 473 MPN/100ml

	Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
			98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
EPA	Avg	Jan	8	9	9	9	8	8	9	11	11	10	9	9	9	9	8	7	7	6	6	6	8.4	62.5	2.6
Moderate	74-78	Feb	9	9	9	9	8	8	8	9	9	8	8	7	7	8	7	7	7	7	7	7	8.0	53.7	2.2
Contract		Mar	12	13	13	13	13	13	15	16	16	14	14	13	12	12	11	11	11	11	10	10	12.7	94.4	3.9
CI 82%		April	18	19	19	18	17	17	17	18	18	17	17	16	15	14	13	12	12	11	11	11	15.4	111.2	4.6
Local Std Dev		May	18	19	19	19	17	17	17	20	20	19	18	16	15	14	14	13	13	12	12	12	16.1	120.1	5.0
		June	21	22	22	22	22	22	23	26	27	26	24	23	21	21	20	19	19	18	18	17	21.7	156.0	6.5
		Jul	19	21	21	19	18	17	19	21	22	20	19	15	13	12	12	11	10	9	8	7	15.7	116.6	4.9
		Aug	23	24	24	24	23	22	25	28	28	26	25	23	22	20	18	17	16	13	12	11	21.1	157.1	6.5
		Sept	13	14	15	15	14	14	18	21	21	18	16	14	13	12	11	10	10	9	8	7	13.5	97.5	4.1
		Oct	16	17	18	18	17	16	18	19	20	18	16	15	14	13	12	12	12	11	10	9	15.0	111.3	4.6
		Nov	15	15	14	13	13	12	12	14	14	13	12	11	9	8	7	7	6	6	6	6	10.7	77.0	3.2
		Dec	15	15	15	15	15	14	16	18	17	16	15	13	12	12	10	10	10	9	9	9	13.2	98.4	4.1

52.3
14.3% Exceed
85.7% Meet

E-Coli - Monthly Geometric Mean (#/100ml)

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Reach		
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8	Average	Peak	
Avg	Jan	56	65	69	67	65	66	72	78	79	77	76	74	73	70	67	64	62	59	57	56	67.6	79.3	
74-78	Feb	54	58	60	60	58	59	62	66	66	64	63	62	61	59	57	56	54	52	50	49	58.4	65.7	
	Mar	56	63	67	66	64	66	74	80	82	80	78	77	76	74	72	70	68	65	64	62	70.1	81.7	
	April	86	91	93	91	89	89	93	97	97	95	93	92	91	88	86	84	82	80	79	77	88.7	97.2	
	May	125	138	146	146	142	144	156	167	168	163	156	149	142	134	125	117	110	104	99	95	136.3	168.3	
	June	114	124	131	130	127	128	138	148	149	144	137	131	126	120	113	107	101	95	91	87	122.1	148.8	
	Jul	111	123	128	124	116	117	129	140	139	130	120	111	104	95	86	78	71	66	63	59	105.6	139.6	
	Aug	164	187	198	193	181	179	191	202	199	187	173	160	150	138	127	116	107	101	95	90	157.0	201.9	
	Sept	73	81	85	82	78	81	92	101	101	95	89	83	80	74	68	63	58	56	54	53	77.4	100.9	
	Oct	78	86	90	86	80	79	85	91	90	85	79	74	70	65	59	54	50	47	45	44	71.8	91.4	43 days>126
	Nov	84	92	94	89	83	81	87	92	91	84	78	72	67	62	56	52	47	44	43	41	71.9	94.2	240 Total Days
	Dec	71	85	93	95	93	95	105	114	116	113	110	107	105	101	96	91	86	81	77	74	95.4	115.8	82.1% Compliance

Illness Rate per 1,000 Swimmers based on E-Coli - Monthly Geometric Mean

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Risk Assessment % of Swimmers	
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8	Average	Peak
Avg	Jan	4.7	5.3	5.5	5.5	5.3	5.3	5.7	6.1	6.1	6.0	5.9	5.8	5.8	5.6	5.4	5.3	5.1	4.9	4.8	4.7	0.54%	0.61%
74-78	Feb	4.5	4.9	5.0	5.0	4.9	4.9	5.1	5.3	5.3	5.2	5.2	5.1	5.0	4.9	4.8	4.7	4.5	4.4	4.3	4.1	0.49%	0.53%
	Mar	4.7	5.2	5.4	5.4	5.2	5.4	5.8	6.2	6.2	6.1	6.1	6.0	5.9	5.9	5.7	5.6	5.5	5.3	5.2	5.1	0.56%	0.62%
	April	6.4	6.7	6.8	6.7	6.6	6.6	6.8	6.9	6.9	6.8	6.8	6.7	6.7	6.6	6.5	6.4	6.3	6.2	6.1	6.0	0.66%	0.69%
	May	8.0	8.4	8.6	8.6	8.5	8.6	8.9	9.2	9.2	9.0	8.9	8.7	8.5	8.3	8.0	7.7	7.5	7.2	7.0	6.8	0.83%	0.92%
	June	7.6	7.9	8.2	8.1	8.0	8.1	8.4	8.7	8.7	8.5	8.4	8.2	8.0	7.8	7.6	7.3	7.1	6.9	6.7	6.5	0.78%	0.87%
	Jul	7.5	7.9	8.1	7.9	7.7	7.7	8.1	8.4	8.4	8.1	7.8	7.5	7.2	6.9	6.5	6.1	5.7	5.4	5.2	4.9	0.71%	0.84%
	Aug	9.1	9.6	9.8	9.7	9.5	9.4	9.7	9.9	9.9	9.6	9.3	9.0	8.7	8.4	8.0	7.7	7.4	7.1	6.9	6.6	0.88%	0.99%
	Sept	5.8	6.2	6.4	6.3	6.1	6.2	6.7	7.1	7.1	6.8	6.6	6.3	6.1	5.9	5.5	5.2	4.9	4.7	4.6	4.4	0.59%	0.71%
	Oct	6.0	6.5	6.6	6.4	6.2	6.1	6.4	6.7	6.6	6.4	6.1	5.8	5.6	5.3	4.9	4.5	4.2	4.0	3.8	3.7	0.56%	0.67%
	Nov	6.4	6.7	6.8	6.6	6.3	6.2	6.5	6.7	6.7	6.4	6.0	5.7	5.4	5.1	4.7	4.4	4.0	3.7	3.6	3.4	0.56%	0.68%
	Dec	5.7	6.4	6.8	6.8	6.8	6.8	7.2	7.6	7.7	7.6	7.4	7.3	7.3	7.1	6.9	6.7	6.4	6.2	6.0	5.8	0.68%	0.77%

City of Richmond, Virginia
Department of Public Utilities
Phase III CSO Control Program

Funded by U.S. Army Corps of Engineers, Norfolk District
Under Contact No. DACW65-01-C-0052

CSO Disinfection Report

Appendix A
Water Quality Model Results
Translated to *E. coli*

Model Runs for
Chlorine Disinfection at Shockoe

FINAL REPORT

June 2005

Greeley and Hansen LLC
with LTI, Inc

City of Richmond, Virginia
Department of Public Utilities
CSO Disinfection Report

James River Water Quality Model Results

Alternative E - South Side Disinfection Facility with Chlorine Dose of 7.0 mg/L

Greeley and Hansen LLC
June 2005

State WQS
CI 75%
State Std Dev

E-Coli - Percent of Time > 235 MPN/100ml

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Reach Average	Hrs/mo	days/yr
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
Avg 74-78	Jan	17	19	20	19	18	18	20	22	23	23	23	22	21	20	19	19	18	18	17	17	19.7	146.3	6.1
	Feb	18	19	20	19	18	18	20	21	21	20	20	20	19	19	17	17	17	16	16	16	18.5	124.3	5.2
	Mar	20	22	24	23	23	23	26	29	29	28	28	28	27	26	25	25	23	22	22	21	24.8	184.3	7.7
	April	28	29	29	28	27	27	28	29	29	27	26	26	25	24	24	23	23	22	21	21	25.8	185.4	7.7
	May	32	33	35	35	34	34	37	40	40	39	38	37	35	34	32	29	28	27	26	25	33.5	248.9	10.4
	June	30	32	33	34	34	33	35	36	37	36	36	36	36	35	34	32	30	29	27	27	33.2	238.9	10.0
	Jul	31	33	34	34	34	33	36	39	38	37	35	33	32	30	29	28	26	24	23	21	31.6	234.9	9.8
	Aug	42	45	48	47	46	45	47	48	48	48	45	42	40	38	38	36	35	34	31	28	41.6	309.2	12.9
	Sept	25	28	29	28	27	28	31	32	33	32	31	30	29	26	24	23	22	21	21	20	27.1	195.0	8.1
	Oct	29	31	31	31	30	31	33	34	34	32	32	29	27	27	26	24	21	20	20	19	28.0	208.4	8.7
	Nov	27	28	29	27	27	25	27	29	28	26	24	23	21	20	19	17	16	15	14	12	22.8	164.1	6.8
	Dec	28	30	31	32	32	32	33	36	35	35	35	35	35	35	33	32	31	29	28	27	32.2	239.6	10.0

103.3
28.3% Exceed
71.7% Meet

State WQS
CI 75%
Local Std Dev

E-Coli - Percent of Time >334 MPN/100ml

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Reach Average	Hrs/mo	days/yr
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
Avg 74-78	Jan	13	15	15	14	13	13	15	17	17	17	16	16	15	14	13	13	13	13	12	12	14.2	105.4	4.4
	Feb	14	15	15	15	15	14	15	16	16	15	15	15	14	15	14	14	13	13	12	10	14.2	95.6	4.0
	Mar	18	20	20	20	20	19	21	23	23	23	21	21	20	20	20	19	18	17	16	15	19.7	146.2	6.1
	April	21	22	22	22	22	22	22	23	23	22	22	22	21	20	20	18	18	17	17	17	20.6	148.4	6.2
	May	24	25	26	26	26	26	28	31	31	30	28	27	25	24	22	21	20	19	19	18	24.8	184.3	7.7
	June	24	26	27	28	28	29	32	33	34	33	32	32	30	29	28	27	25	24	24	23	28.4	204.6	8.5
	Jul	27	28	29	29	28	28	30	32	32	31	31	28	26	25	23	21	19	18	18	17	26.0	193.3	8.1
	Aug	35	38	41	40	38	36	38	40	40	39	37	35	32	30	28	27	26	25	24	23	33.6	250.0	10.4
	Sept	19	20	22	22	22	22	25	28	28	27	26	25	22	22	21	18	17	17	15	14	21.6	155.8	6.5
	Oct	22	24	25	25	25	25	26	29	29	28	27	26	24	21	20	19	19	18	16	15	23.2	172.8	7.2
	Nov	23	24	24	22	20	20	20	22	20	18	16	15	14	14	12	10	10	10	9	9	16.6	119.5	5.0
	Dec	23	25	26	26	25	26	27	30	30	30	29	28	27	26	24	22	22	20	19	18	25.2	187.3	7.8

81.8
22.4% Exceed
77.6% Meet

EPA
Moderate
Contract
CI 82%
State Std Dev

E-coli - Percent of Time > 298 MPN/100ml

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
Avg 74-78	Jan	14	15	16	15	15	14	16	19	19	18	18	17	16	16	16	15	13	13	13	13	15.7	116.4	4.9
	Feb	14	15	16	16	15	15	16	18	18	17	17	16	16	16	15	15	15	15	14	14	15.5	104.1	4.3
	Mar	19	20	22	21	21	21	23	25	26	24	24	23	23	23	22	21	21	20	19	18	21.8	162.2	6.8
	April	23	23	23	23	22	22	23	24	24	23	23	22	22	21	21	21	20	20	20	18	21.8	157.3	6.6
	May	27	28	30	29	28	29	31	34	34	32	31	31	28	26	24	23	22	21	20	20	27.4	203.7	8.5
	June	26	28	30	29	30	31	33	34	35	35	34	33	32	30	29	28	27	26	25	24	29.9	215.1	9.0
	Jul	29	30	31	30	29	30	32	34	34	32	31	31	29	27	25	23	22	20	18	18	27.8	206.8	8.6
	Aug	37	40	43	42	41	41	42	44	42	41	39	37	35	33	32	30	28	27	26	24	36.1	268.9	11.2
	Sept	22	24	24	24	23	24	27	29	30	29	28	27	25	23	22	20	18	18	17	16	23.4	168.7	7.0
	Oct	24	26	27	27	26	26	27	30	31	30	29	27	26	25	22	20	19	19	18	17	24.8	184.6	7.7
	Nov	25	26	25	24	23	22	22	24	23	21	19	17	17	16	14	12	11	10	10	10	18.6	134.1	5.6
	Dec	24	26	28	28	28	28	30	32	32	32	31	31	30	29	28	26	25	23	22	21	27.7	205.7	8.6

88.6
24.3% Exceed
75.7% Meet

EPA
Moderate
Contract
CI 82%
Local Std Dev

E-coli - Percent of Time > 473 MPN/100ml

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
Avg 74-78	Jan	11	12	11	11	10	10	11	13	13	12	11	11	11	11	10	10	9	9	8	9	10.6	79.0	3.3
	Feb	9	10	10	9	9	9	9	10	10	9	8	8	8	8	8	8	7	7	7	7	8.5	56.9	2.4
	Mar	14	15	16	15	15	15	17	18	18	17	16	16	15	15	14	13	12	13	12	12	15.0	111.4	4.6
	April	19	21	20	19	18	18	18	20	19	19	18	18	17	16	15	14	14	13	12	12	17.0	122.2	5.1
	May	19	20	21	21	20	20	20	22	22	20	19	18	16	14	15	15	15	14	14	14	17.9	133.1	5.5
	June	23	24	25	24	25	25	27	29	30	29	27	26	24	23	22	21	21	22	21	21	24.4	175.4	7.3
	Jul	24	25	25	24	23	22	23	25	25	23	23	21	20	19	19	18	16	15	14	12	20.8	154.9	6.5
	Aug	28	30	31	30	28	28	30	32	33	31	29	27	26	24	23	22	21	19	18	16	26.2	194.7	8.1
	Sept	16	17	19	18	17	17	21	24	24	22	20	18	17	15	14	14	13	12	10	9	16.9	121.9	5.1
	Oct	19	20	22	22	20	19	21	23	23	22	19	18	18	17	16	15	15	14	12	11	18.3	136.0	5.7
	Nov	17	16	16	15	14	13	13	15	15	14	13	12	10	8	8	7	6	7	7	7	11.6	83.4	3.5
	Dec	18	19	20	20	20	20	22	24	23	22	21	18	17	17	15	15	15	14	14	14	18.4	137.2	5.7

62.8
17.2% Exceed
82.8% Meet

E-Coli - Monthly Geometric Mean (#/100ml)

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Reach Average	Peak	
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
Avg 74-78	Jan	62	72	76	74	72	72	78	85	86	83	82	80	79	76	73	70	68	65	63	61	73.8	85.5	
	Feb	55	60	62	61	60	60	64	67	67	65	64	63	62	61	59	57	56	54	52	50	60.0	67.1	
	Mar	61	69	73	72	70	73	81	88	89	87	85	83	82	80	77	75	73	70	69	67	76.2	89.2	
	April	92	97	99	97	95	94	99	103	103	100	99	97	96	93	91	89	87	85	83	82	94.1	102.8	
	May	134	148	157	158	154	155	167	179	179	173	166	158	150	141	131	123	115	108	103	99	145.0	179.5	
	June	126	138	145	145	141	142	152	162	164	158	152	145	139	133	125	118	112	106	101	98	135.0	163.5	
	Jul	145	160	165	159	150	149	161	171	169	158	147	137	128	119	108	99	91	85	80	76	132.8	171.1	
	Aug	226	257	270	263	248	243	253	264	258	241	222	205	192	177	162	149	138	130	123	117	207.0	270.1	
	Sept	93	104	108	104	99	103	116	127	128	121	114	109	105	98	91	83	77	74	71	69	99.7	128.4	
	Oct	99	109	112	107	99	96	103	109	106	100	93	87	82	76	69	64	59	55	53	52	86.4	111.6	65 days>126
	Nov	95	103	104	97	90	87	92	97	95	88	81	75	70	64	59	54	50	47	45	44	76.8	103.7	240 Total Days
	Dec	83	100	110	111	110	112	123	133	135	132	129	126	123	119	114	107	102	96	92	88	112.2	135.3	72.9% Compliance

Illness Rate per 1,000 Swimmers based on E-Coli - Monthly Geometric Mean

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Risk Assessment % of Swimmers Average	Peak
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8		
Avg 74-78	Jan	5.1	5.7	5.9	5.8	5.7	5.7	6.1	6.4	6.4	6.3	6.3	6.2	6.1	5.9	5.8	5.6	5.5	5.3	5.2	5.1	0.58%	0.64%
	Feb	4.6	5.0	5.1	5.1	5.0	5.0	5.2	5.4	5.4	5.3	5.3	5.2	5.1	5.0	4.9	4.8	4.7	4.5	4.4	4.3	0.50%	0.54%
	Mar	5.0	5.6	5.8	5.7	5.6	5.8	6.2	6.5	6.6	6.5	6.4	6.3	6.3	6.2	6.0	5.9	5.8	5.6	5.5	5.4	0.59%	0.66%
	April	6.7	6.9	7.0	6.9	6.8	6.8	7.0	7.2	7.2	7.1	7.0	6.9	6.9	6.8	6.7	6.6	6.5	6.4	6.3	6.2	0.68%	0.72%
	May	8.3	8.7	8.9	8.9	8.8	8.9	9.2	9.4	9.5	9.3	9.1	8.9	8.7	8.5	8.2	7.9	7.6	7.4	7.2	7.0	0.85%	0.95%
	June	8.0	8.4	8.6	8.6	8.5	8.5	8.8	9.0	9.1	8.9	8.8	8.6	8.4	8.2	8.0	7.8	7.5	7.3	7.1	7.0	0.82%	0.91%
	Jul	8.6	9.0	9.1	9.0	8.7	8.7	9.0	9.3	9.2	8.9	8.6	8.3	8.1	7.8	7.4	7.0	6.7	6.4	6.2	6.0	0.81%	0.93%
	Aug	10.4	10.9	11.1	11.0	10.8	10.7	10.9	11.0	10.9	10.7	10.3	10.0	9.7	9.4	9.0	8.7	8.4	8.1	7.9	7.7	0.99%	1.11%
	Sept	6.7	7.2	7.4	7.2	7.0	7.2	7.7	8.0	8.1	7.9	7.6	7.4	7.2	7.0	6.7	6.3	6.0	5.8	5.7	5.6	0.70%	0.81%
	Oct	7.0	7.4	7.5	7.3	7.0	6.9	7.2	7.4	7.3	7.1	6.8	6.5	6.3	6.0	5.6	5.2	4.9	4.6	4.5	4.4	0.63%	0.75%
	Nov	6.8	7.2	7.2	7.0	6.6	6.5	6.7	6.9	6.9	6.6	6.2	5.9	5.6	5.3	4.9	4.6	4.2	4.0	3.8	3.7	0.58%	0.72%
	Dec	6.3	7.1	7.4	7.5	7.4	7.5	7.9	8.2	8.3	8.2	8.1	8.0	7.9	7.8	7.6	7.4	7.1	6.9	6.7	6.5	0.75%	0.83%

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City of Richmond, Virginia
Department of Public Utilities
CSO Disinfection Report

James River Water Quality Model Results

Alternative E -SSDF & Shockoe Expansion with No Disinfection

Greeley and Hansen LLC
June 2005

State WQS
CI 75%
State Std Dev

E-Coli - Percent of Time > 235 MPN/100ml																								
Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Reach		
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8	Average	Hrs/mo	days/yr
Avg	Jan	16	18	19	18	18	17	19	22	22	22	22	21	20	19	19	19	18	17	17	17	19.0	141.7	5.9
74-78	Feb	17	19	19	18	17	17	19	21	21	20	19	19	18	18	17	16	16	16	15	15	17.9	120.2	5.0
	Mar	19	22	23	23	23	22	25	28	28	28	27	26	26	25	24	23	22	21	21	20	23.8	177.4	7.4
	April	28	29	29	27	27	27	27	29	29	27	26	25	24	24	23	23	22	21	21	21	25.5	183.3	7.6
	May	31	32	34	34	33	33	36	38	38	37	36	35	34	33	30	28	27	25	25	25	32.2	239.2	10.0
	June	29	31	32	33	32	32	34	36	36	36	36	36	35	35	33	31	30	28	27	26	32.3	232.8	9.7
	Jul	30	32	34	34	32	33	35	39	38	36	34	32	31	30	28	27	25	24	23	20	30.7	228.5	9.5
	Aug	40	43	45	45	43	43	46	48	48	47	44	41	39	38	37	35	34	32	30	27	40.1	298.0	12.4
	Sept	24	27	29	28	27	27	30	31	32	31	30	29	28	25	23	23	22	21	20	20	26.3	189.0	7.9
	Oct	27	29	29	30	28	28	31	33	33	31	31	29	27	26	26	24	21	20	20	19	27.1	201.8	8.4
	Nov	26	27	28	27	26	24	26	29	28	26	24	23	21	20	19	17	16	15	14	12	22.5	161.7	6.7
	Dec	26	28	30	31	30	30	32	35	34	34	33	33	33	33	31	29	28	27	26	26	30.5	227.1	9.5

100.0
27.4% Exceed
72.6% Meet

State WQS
CI 75%
Local Std Dev

E-Coli - Percent of Time >334 MPN/100ml																								
Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
Avg	Jan	12	13	13	13	12	12	14	17	16	16	16	16	15	14	13	13	13	13	12	12	13.7	101.6	4.2
74-78	Feb	14	14	14	14	14	14	14	16	16	15	15	14	14	14	14	13	13	12	11	10	13.8	92.5	3.9
	Mar	18	19	19	19	19	18	20	22	22	22	20	21	19	19	19	19	17	16	15	14	18.9	140.8	5.9
	April	21	22	22	22	22	22	22	23	23	22	21	21	21	20	20	18	18	17	17	16	20.4	146.8	6.1
	May	23	24	25	25	25	25	27	30	29	28	27	26	24	22	21	20	19	19	18	18	23.7	176.5	7.4
	June	23	25	26	27	27	27	30	32	33	31	30	30	29	28	26	25	25	24	23	22	27.1	195.2	8.1
	Jul	26	27	28	28	27	27	28	31	31	30	30	27	25	24	22	21	19	17	17	15	24.9	185.6	7.7
	Aug	33	36	38	36	34	34	36	38	39	37	36	33	31	28	27	25	25	23	22	21	31.7	235.5	9.8
	Sept	19	20	21	21	20	21	25	27	28	26	25	24	22	21	20	18	17	16	15	14	21.0	151.0	6.3
	Oct	21	22	23	23	23	23	25	28	28	28	27	25	24	21	20	19	19	18	16	15	22.3	166.2	6.9
	Nov	22	22	23	21	19	18	20	22	20	18	16	15	14	14	12	10	10	10	9	9	16.2	116.3	4.8
	Dec	21	23	25	25	24	24	26	29	29	29	28	27	25	23	22	21	20	18	18	17	23.7	176.3	7.3

78.5
21.5% Exceed
78.5% Meet

EPA
Moderate
Contract
CI 82%
State Std Dev

E-coli - Percent of Time > 298 MPN/100ml																								
Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
Avg	Jan	13	15	15	14	14	14	15	18	19	17	17	17	16	15	16	15	13	13	13	13	15.1	112.4	4.7
74-78	Feb	14	15	15	15	14	14	15	17	17	17	16	15	15	15	15	14	15	14	13	13	14.9	100.4	4.2
	Mar	18	20	21	20	21	20	22	24	25	24	23	22	22	22	21	21	20	19	18	18	21.0	155.9	6.5
	April	22	23	23	22	22	22	23	24	24	23	22	22	22	21	21	20	20	20	20	18	21.7	155.9	6.5
	May	26	28	29	28	27	27	30	32	32	30	30	29	27	24	23	22	21	21	20	19	26.3	195.9	8.2
	June	24	26	28	28	29	29	31	33	34	34	33	32	31	29	28	26	26	25	25	24	28.7	206.4	8.6
	Jul	28	29	31	29	28	29	31	33	33	31	30	29	28	26	23	22	21	19	18	17	26.8	199.5	8.3
	Aug	35	38	40	40	38	38	41	43	41	40	38	36	34	32	30	29	26	25	24	23	34.5	256.7	10.7
	Sept	22	23	23	23	22	22	26	28	29	28	26	26	23	23	22	20	18	18	17	16	22.7	163.6	6.8
	Oct	23	24	25	25	23	24	26	29	30	29	28	27	26	24	22	20	19	18	18	17	23.9	177.6	7.4
	Nov	24	25	24	23	22	21	22	24	23	21	19	17	17	16	14	12	11	10	10	10	18.2	131.4	5.5
	Dec	23	24	26	27	26	27	29	31	31	30	30	29	28	26	25	25	24	22	21	20	26.1	194.2	8.1

85.4
23.4% Exceed
76.6% Meet

EPA
Moderate
Contract
CI 82%
Local Std Dev

E-coli - Percent of Time > 473 MPN/100ml																								
Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
Avg	Jan	10	11	10	10	9	9	10	12	12	11	11	10	11	10	9	10	9	8	8	9	9.9	74.0	3.1
74-78	Feb	9	9	9	9	8	8	8	10	9	9	8	8	8	8	7	7	7	7	7	7	8.1	54.7	2.3
	Mar	14	15	15	15	15	15	16	18	18	16	16	15	15	14	13	12	12	12	12	11	14.4	106.9	4.5
	April	19	20	20	19	18	18	18	20	19	19	18	17	16	16	14	14	13	12	12	12	16.7	120.4	5.0
	May	18	19	20	20	19	19	19	20	20	20	18	17	15	14	14	14	14	14	14	14	17.1	127.2	5.3
	June	22	23	24	23	23	23	24	27	28	27	26	25	23	22	21	21	21	21	21	21	23.2	167.2	7.0
	Jul	23	24	24	22	22	21	22	24	24	22	22	20	20	18	18	16	15	12	12	12	19.6	145.7	6.1
	Aug	26	28	28	27	27	26	27	31	31	29	27	25	25	23	22	21	20	18	18	16	24.7	183.7	7.7
	Sept	15	16	18	18	17	17	20	23	23	21	20	17	16	15	14	14	13	12	10	9	16.4	118.4	4.9
	Oct	18	19	20	20	19	19	20	22	22	21	18	18	17	16	16	15	15	14	12	11	17.5	129.8	5.4
	Nov	16	16	15	14	14	13	13	15	14	14	13	12	10	8	8	7	6	7	7	7	11.3	81.5	3.4
	Dec	17	17	18	18	18	17	19	21	21	20	18	17	16	15	15	14	14	14	13	13	16.8	124.8	5.2

59.8
16.4% Exceed
83.6% Meet

E-Coli - Monthly Geometric Mean (#/100ml)																								
Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Reach		
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8	Average	Peak	
Avg	Jan	60	70	74	72	70	70	77	83	84	82	81	79	77	74	71	68	66	63	61	60	72.1	84.0	
74-78	Feb	54	59	61	60	59	59	63	66	66	64	63	62	61	59	58	56	54	52	51	49	58.7	65.9	
	Mar	59	67	71	70	68	70	78	84	86	84	82	80	79	78	75	72	70	68	66	64	73.5	85.9	
	April	91	95	97	96	93	93	98	102	102	99	98	96	95	92	90	88	86	84	83	81	92.9	101.6	
	May	128	142	151	151	147	149	161	173	174	168	161	153	146	138	129	120	113	106	102	97	140.4	173.6	
	June	120	131	138	138	134	135	145	155	157	151	145	139	134	127	120	114	108	102	98	95	129.5	156.7	
	Jul	136	151	156	151	143	142	154	165	163	152	141	131	123	113	103	94	86	80	75	71	126.6	164.7	
	Aug	203	232	245	239	225	222	235	247	244	228	211	195	183	169	154	142	131	123	118	112	192.8	247.1	
	Sept	87	98	102	99	95	99	112	124	125	119	112	107	103	96	89	82	76	72	70	68	96.7	125.5	
	Oct	93	104	107	102	95	92	99	105	103	97	90	84	80	74	67	62	57	53	51	50	83.2	106.6	59 days>126
	Nov	89	98	99	94	87	85	90	96	94	87	80	74	69	64	59	54	50	47	45	43	75.2	99.4	240 Total Days
	Dec	78	94	104	105	104	106	116	127	128	125	122	119	117	113	107	101	96	90	86	83	106.1	128.4	75.4% Compliance

Illness Rate per 1,000 Swimmers based on E-Coli - Monthly Geometric Mean																					Risk Assessment	
Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	% of Swimmers	
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8	Average	Peak
Avg	Jan	5.0	5.6	5.8	5.7	5.6	5.6	6.0	6.3	6.4	6.3	6.2	6.1	6.0	5.9	5.7	5.5	5.4	5.2	5.1	4.9	0.57%	0.64%
74-78	Feb	4.5	4.9	5.0	5.0	4.9	4.9	5.2	5.4	5.4	5.3	5.2	5.1	5.0	4.9	4.8	4.7	4.6	4.4	4.3	4.2	0.49%	0.54%
	Mar	4.9	5.4	5.6	5.6	5.5	5.6	6.0	6.4	6.4	6.3	6.2	6.2	6.1	6.0	5.9	5.7	5.6	5.5	5.4	5.3	0.58%	0.64%
	April	6.7	6.9	7.0	6.9	6.8	6.8	7.0	7.1	7.1	7.0	7.0	6.9	6.8	6.7	6.6	6.6	6.5	6.4	6.3	6.2	0.68%	0.71%
	May	8.1	8.5	8.7	8.7	8.6	8.7	9.0	9.3	9.3	9.2	9.0	8.8	8.6	8.4	8.1	7.8	7.6	7.3	7.1	7.0	0.84%	0.93%
	June	7.8	8.2	8.4	8.4	8.3	8.3	8.6	8.9	8.9	8.8	8.6	8.4	8.3	8.1	7.8	7.6	7.4	7.2	7.0	6.8	0.81%	0.89%
	Jul	8.3	8.7	8.9	8.8	8.5	8.5	8.8	9.1	9.1	8.8	8.5	8.2	7.9	7.6	7.2	6.8	6.4	6.1	5.9	5.7	0.79%	0.91%
	Aug	10.0	10.5	10.7	10.6	10.4	10.3	10.6	10.8	10.7	10.4	10.1	9.8	9.5	9.2	8.8	8.5	8.2	7.9	7.7	7.5	0.96%	1.08%
	Sept	6.5	7.0	7.2	7.0	6.9	7.0	7.5	7.9	8.0	7.8	7.5	7.3	7.2	6.9	6.6	6.2	5.9	5.7	5.6	5.5	0.69%	0.80%
	Oct	6.8	7.2	7.3	7.1	6.8	6.7	7.0	7.3	7.2	6.9	6.6	6.3	6.1	5.8	5.4	5.1	4.8	4.5	4.3	4.2	0.62%	0.73%
	Nov	6.6	7.0	7.0	6.8	6.5	6.4	6.6	6.9	6.8	6.5	6.2	5.9	5.6	5.2	4.9	4.5	4.2	4.0	3.8	3.6	0.57%	0.70%
	Dec	6.1	6.8	7.2	7.3	7.2	7.3	7.7	8.0	8.1	8.0	7.9	7.8	7.7	7.6	7.3	7.1	6.9	6.7	6.5	6.3	0.73%	0.81%

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City of Richmond, Virginia
Department of Public Utilities
CSO Disinfection Report

James River Water Quality Model Results

Alternative E -SSDF & Shockoe Expansion with Chlorine Dose at 5.0 mg/L

Greeley and Hansen LLC
June 2005

E-Coli - Percent of Time > 235 MPN/100ml

	Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Reach		
			98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8	Average	Hrs/mo	days/yr
State WQS	Avg	Jan	15	17	19	18	17	17	19	21	22	22	22	20	19	18	18	18	17	17	16	16	18.4	136.7	5.7
CI 75%	74-78	Feb	17	19	19	18	17	17	19	21	21	19	19	19	18	18	17	16	16	16	15	15	17.7	119.2	5.0
State Std Dev		Mar	18	21	22	22	22	21	24	27	28	27	26	25	25	24	23	22	21	20	19	19	22.8	169.3	7.1
		April	27	28	29	27	26	26	26	28	28	26	26	24	23	23	22	22	21	20	20	19	24.7	177.8	7.4
		May	31	31	33	33	33	33	35	38	38	36	35	35	33	32	29	27	26	25	25	25	31.8	236.2	9.8
		June	28	30	31	31	32	31	33	35	36	36	35	35	35	33	31	30	29	27	26	26	31.5	226.7	9.4
		Jul	28	31	32	32	31	31	34	37	36	35	33	31	29	28	27	25	22	21	20	19	29.1	216.4	9.0
		Aug	38	42	44	44	42	42	45	47	47	46	43	41	38	36	35	33	32	29	28	25	38.8	288.4	12.0
		Sept	22	25	27	26	24	25	27	28	29	28	27	26	25	22	21	21	19	18	18	16	23.7	170.7	7.1
		Oct	25	27	28	28	27	27	29	32	31	30	30	27	26	25	25	23	20	19	18	17	25.7	191.0	8.0
		Nov	26	26	27	26	25	24	25	28	27	25	23	22	21	19	18	17	16	14	13	12	21.7	156.4	6.5
		Dec	23	26	28	29	28	28	30	33	32	32	31	30	30	29	27	25	24	23	22	22	27.7	206.1	8.6

95.6
26.2% Exceed
73.8% Meet

E-Coli - Percent of Time >334 MPN/100ml

	Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
			98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
State WQS	Avg	Jan	11	12	13	12	12	11	13	16	16	15	15	14	13	13	12	11	11	11	11	10	12.6	93.8	3.9
CI 75%	74-78	Feb	14	14	14	14	14	13	14	15	15	15	15	14	14	14	13	13	13	12	11	10	13.6	91.3	3.8
Local Std Dev		Mar	17	18	18	18	18	17	18	21	21	20	19	19	18	18	17	17	15	14	13	13	17.4	129.8	5.4
		April	20	21	22	21	21	21	21	22	22	21	20	20	20	19	18	17	17	15	15	15	19.4	139.8	5.8
		May	23	24	24	24	24	24	26	29	28	28	27	25	23	21	20	19	18	18	18	17	22.9	170.6	7.1
		June	22	24	26	26	26	26	29	31	32	31	30	29	28	26	25	24	23	22	22	21	26.0	187.2	7.8
		Jul	24	26	27	26	24	24	27	29	28	28	27	25	23	21	18	16	15	13	13	12	22.2	165.2	6.9
		Aug	31	34	36	35	32	32	35	38	38	36	33	31	29	27	26	24	23	22	21	20	30.1	224.2	9.3
		Sept	17	18	19	19	18	18	22	24	25	24	23	22	20	19	17	15	15	13	11	11	18.6	133.7	5.6
		Oct	19	20	21	21	21	21	24	26	26	26	25	23	21	19	18	17	15	15	14	13	20.3	151.3	6.3
		Nov	22	22	22	20	18	17	19	21	19	18	15	14	13	13	10	10	9	9	9	9	15.5	111.3	4.6
		Dec	19	21	22	22	21	21	24	26	27	26	24	23	21	20	18	17	16	14	13	12	20.3	151.2	6.3

72.9
20.0% Exceed
80.0% Meet

E-coli - Percent of Time > 298 MPN/100ml

	Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
			98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
EPA	Avg	Jan	11	14	14	13	13	13	15	18	18	17	16	16	15	15	15	14	12	12	12	12	14.2	105.8	4.4
Moderate	74-78	Feb	14	15	15	15	14	14	15	17	17	16	16	15	15	15	14	14	14	14	13	13	14.7	99.0	4.1
Contract		Mar	17	19	20	19	19	19	21	23	23	22	21	21	20	20	19	19	18	18	16	16	19.6	145.6	6.1
CI 82%		April	21	22	22	22	22	21	22	23	23	22	22	21	21	20	20	19	19	18	18	16	20.7	149.3	6.2
State Std Dev		May	26	27	28	27	27	27	29	32	31	30	30	29	26	23	22	21	21	21	20	19	25.8	192.0	8.0
		June	23	25	27	27	28	28	30	32	33	33	32	31	30	28	26	25	24	24	23	23	27.7	199.3	8.3
		Jul	26	28	29	27	26	27	29	31	31	29	28	27	26	24	20	18	18	16	15	13	24.5	182.2	7.6
		Aug	33	36	39	38	37	37	40	42	40	39	37	34	31	30	28	27	25	23	22	21	33.0	245.7	10.2
		Sept	20	21	21	21	19	19	24	25	27	25	24	23	21	20	20	18	15	15	15	12	20.3	146.2	6.1
		Oct	21	22	23	23	22	22	25	28	28	28	27	26	25	23	19	18	17	16	15	15	22.2	164.8	6.9
		Nov	23	24	24	23	21	20	21	23	22	20	18	16	16	15	13	11	10	10	10	9	17.4	125.6	5.2
		Dec	20	22	24	25	24	24	27	29	29	28	27	26	24	23	21	20	19	17	16	15	23.0	170.9	7.1

80.3
22.0% Exceed
78.0% Meet

E-coli - Percent of Time > 473 MPN/100ml

	Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
			98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
EPA	Avg	Jan	9	9	9	9	8	8	9	11	11	10	9	9	9	9	8	7	7	6	6	6	8.4	62.8	2.6
Moderate	74-78	Feb	9	9	9	9	8	8	8	9	9	8	8	7	7	8	7	7	7	7	7	7	8.0	53.7	2.2
Contract		Mar	12	13	14	13	13	13	15	16	16	14	14	13	13	12	11	11	11	11	10	10	12.7	94.4	3.9
CI 82%		April	18	19	19	18	17	17	17	18	18	17	17	16	15	14	13	12	12	11	11	11	15.5	111.5	4.6
Local Std Dev		May	18	19	19	19	17	17	18	20	20	19	18	16	15	14	14	14	13	13	12	12	16.3	121.0	5.0
		June	21	22	22	22	22	22	23	26	27	26	25	23	22	21	20	20	19	19	19	18	22.0	158.2	6.6
		Jul	20	21	22	20	19	17	19	22	22	20	19	17	15	13	12	12	11	10	10	9	16.5	123.0	5.1
		Aug	24	26	26	25	24	23	25	28	29	27	25	24	23	22	21	19	18	17	16	14	22.8	169.5	7.1
		Sept	13	14	15	15	14	14	18	21	21	18	16	15	13	13	12	10	10	9	8	7	13.8	99.6	4.2
		Oct	16	17	18	18	17	16	18	20	20	18	16	15	14	14	12	12	12	12	11	9	15.2	113.2	4.7
		Nov	15	15	14	13	13	12	12	14	14	13	12	11	9	8	7	7	6	6	6	6	10.7	77.1	3.2
		Dec	15	15	15	15	15	14	16	18	17	16	15	13	12	12	10	10	10	9	9	9	13.3	98.7	4.1

53.5
14.6% Exceed
85.4% Meet

E-Coli - Monthly Geometric Mean (#/100ml)

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Reach		
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8	Average	Peak	
Avg	Jan	56	65	69	68	65	66	72	79	79	77	76	74	73	70	67	64	62	59	58	56	67.8	79.4	
74-78	Feb	54	58	60	60	58	59	62	66	66	64	63	62	61	59	57	56	54	52	50	49	58.4	65.7	
	Mar	56	63	67	66	64	66	74	80	82	80	78	77	76	74	72	70	68	65	64	62	70.1	81.8	
	April	86	91	93	92	89	89	93	97	97	95	93	92	91	88	86	85	83	80	79	77	88.8	97.3	
	May	125	138	147	147	143	145	156	168	169	163	157	150	143	134	126	118	111	104	99	95	136.9	169.1	
	June	115	125	132	131	128	128	139	148	150	145	138	132	127	121	114	108	102	97	93	89	123.1	149.7	
	Jul	116	129	134	130	122	123	135	146	145	136	125	116	109	100	91	82	75	70	66	63	110.7	145.9	
	Aug	183	209	221	216	204	202	215	228	225	211	195	180	169	157	144	132	122	114	108	103	176.9	227.5	
	Sept	74	83	87	84	79	82	93	103	103	98	92	87	83	78	72	67	62	59	58	56	80.0	103.5	
	Oct	80	89	92	88	82	81	87	93	92	86	80	75	71	66	60	55	51	47	46	45	73.3	93.3	47 days>126
	Nov	84	92	94	89	83	81	87	92	91	85	78	72	67	62	57	52	48	45	43	42	72.2	94.3	240 Total Days
	Dec	71	85	94	95	93	95	105	114	116	113	110	107	105	101	96	91	86	81	77	74	95.5	115.9	80.4% Compliance

Illness Rate per 1,000 Swimmers based on E-Coli - Monthly Geometric Mean

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Risk Assessment % of Swimmers	
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8	Average	Peak
Avg	Jan	4.7	5.3	5.5	5.5	5.3	5.4	5.7	6.1	6.1	6.0	5.9	5.8	5.8	5.6	5.4	5.3	5.1	4.9	4.8	4.7	0.54%	0.61%
74-78	Feb	4.5	4.9	5.0	5.0	4.9	4.9	5.1	5.3	5.3	5.2	5.2	5.1	5.0	4.9	4.8	4.7	4.5	4.4	4.3	4.1	0.49%	0.53%
	Mar	4.7	5.2	5.4	5.4	5.2	5.4	5.8	6.2	6.2	6.1	6.1	6.0	5.9	5.9	5.7	5.6	5.5	5.3	5.2	5.1	0.56%	0.62%
	April	6.5	6.7	6.8	6.7	6.6	6.6	6.8	7.0	7.0	6.9	6.8	6.7	6.7	6.6	6.5	6.4	6.3	6.2	6.1	6.0	0.66%	0.70%
	May	8.0	8.4	8.6	8.6	8.5	8.6	8.9	9.2	9.2	9.1	8.9	8.7	8.5	8.3	8.0	7.7	7.5	7.2	7.0	6.9	0.83%	0.92%
	June	7.6	8.0	8.2	8.2	8.1	8.1	8.4	8.7	8.7	8.6	8.4	8.2	8.0	7.8	7.6	7.4	7.1	6.9	6.7	6.6	0.79%	0.87%
	Jul	7.7	8.1	8.3	8.1	7.9	7.9	8.3	8.6	8.6	8.3	8.0	7.7	7.4	7.1	6.7	6.3	5.9	5.6	5.4	5.2	0.73%	0.86%
	Aug	9.5	10.1	10.3	10.2	10.0	9.9	10.2	10.4	10.4	10.1	9.8	9.5	9.2	8.9	8.5	8.2	7.9	7.6	7.4	7.2	0.93%	1.04%
	Sept	5.8	6.3	6.5	6.3	6.1	6.3	6.8	7.2	7.2	7.0	6.7	6.5	6.3	6.1	5.7	5.4	5.1	4.9	4.8	4.7	0.61%	0.72%
	Oct	6.1	6.6	6.7	6.5	6.3	6.2	6.5	6.8	6.7	6.5	6.2	5.9	5.7	5.4	5.0	4.6	4.3	4.0	3.9	3.8	0.57%	0.68%
	Nov	6.4	6.7	6.8	6.6	6.3	6.2	6.5	6.7	6.7	6.4	6.0	5.7	5.4	5.1	4.8	4.4	4.1	3.8	3.6	3.5	0.56%	0.68%
	Dec	5.7	6.4	6.8	6.8	6.8	6.8	7.3	7.6	7.7	7.6	7.5	7.3	7.3	7.1	6.9	6.7	6.4	6.2	6.0	5.8	0.68%	0.77%

City of Richmond, Virginia
Department of Public Utilities
CSO Disinfection Report

James River Water Quality Model Results

Alternative E -SSDF & Shockoe Expansion with Chlorine Dose at 5.75 mg/L

Greeley and Hansen LLC
June 2005

State WQS
CI 75%
State Std Dev

E-Coli - Percent of Time > 235 MPN/100ml

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Reach Average	Hrs/mo	days/yr
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
Avg	Jan	15	17	19	18	17	17	19	21	22	22	22	20	19	18	18	18	17	17	16	16	18.4	136.6	5.7
74-78	Feb	17	19	19	18	17	17	19	21	21	19	19	19	18	18	17	16	16	16	15	15	17.7	119.2	5.0
	Mar	18	21	22	22	22	21	24	27	28	27	26	25	25	24	23	22	21	20	19	19	22.8	169.3	7.1
	April	27	28	29	27	26	26	26	28	28	26	26	24	23	23	22	22	21	20	20	19	24.7	177.6	7.4
	May	31	31	33	33	33	33	35	38	38	36	35	34	33	32	29	27	26	25	25	25	31.7	235.7	9.8
	June	28	30	31	31	32	31	33	35	36	35	35	35	34	33	31	30	29	27	26	25	31.4	225.8	9.4
	Jul	28	31	32	32	30	31	34	37	36	34	32	31	29	28	27	24	21	21	20	19	28.7	213.7	8.9
	Aug	38	42	44	43	42	42	45	47	47	46	43	40	38	35	34	32	31	29	27	24	38.4	285.7	11.9
	Sept	22	25	26	26	24	24	26	28	29	28	27	25	25	22	21	20	19	18	18	16	23.5	169.3	7.1
	Oct	25	26	27	28	26	27	29	32	31	30	29	27	26	25	25	23	20	19	18	17	25.5	190.1	7.9
	Nov	26	26	27	26	25	24	25	28	27	25	23	22	21	19	18	17	16	14	12	12	21.7	156.2	6.5
	Dec	23	26	28	29	28	28	30	33	32	32	31	30	30	29	27	25	24	23	22	22	27.6	205.6	8.6

95.2
26.1% Exceed
73.9% Meet

State WQS
CI 75%
Local Std Dev

E-Coli - Percent of Time >334 MPN/100ml

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
Avg	Jan	11	12	13	12	12	11	13	16	16	15	15	14	13	13	12	11	11	11	11	10	12.6	93.8	3.9
74-78	Feb	14	14	14	14	14	13	14	15	15	15	15	14	14	14	13	13	13	12	11	10	13.6	91.3	3.8
	Mar	17	18	18	18	18	17	18	21	21	20	19	19	18	17	17	17	15	14	13	13	17.4	129.6	5.4
	April	20	21	22	21	21	21	21	22	22	21	20	20	20	19	18	17	17	15	15	15	19.4	139.6	5.8
	May	23	24	24	24	24	24	26	29	28	28	27	25	23	21	20	18	18	18	17	16	22.7	169.2	7.0
	June	22	24	26	26	26	26	29	31	32	30	30	29	28	26	25	24	22	21	21	20	25.9	186.1	7.8
	Jul	24	25	26	26	24	24	26	28	28	27	27	24	22	19	17	15	14	13	12	12	21.7	161.6	6.7
	Aug	31	34	36	35	32	32	35	37	38	35	33	30	28	27	25	24	23	21	20	20	29.8	221.4	9.2
	Sept	17	18	19	19	18	18	22	24	25	24	23	22	20	19	17	15	14	13	11	11	18.4	132.3	5.5
	Oct	19	20	21	21	21	21	24	26	26	26	25	23	21	18	18	17	15	15	14	13	20.2	150.4	6.3
	Nov	22	22	22	20	18	17	19	21	19	18	15	14	13	13	10	10	9	9	9	8	15.4	111.1	4.6
	Dec	19	21	22	22	21	21	24	26	27	26	24	23	21	20	18	17	16	14	13	12	20.3	150.9	6.3

72.4
19.8% Exceed
80.2% Meet

EPA
Moderate
Contract
CI 82%
State Std Dev

E-coli - Percent of Time > 298 MPN/100ml

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
Avg	Jan	11	14	14	13	13	13	15	18	18	17	16	16	15	15	15	14	12	12	12	11	14.2	105.4	4.4
74-78	Feb	14	15	15	15	14	14	15	17	17	16	16	15	15	15	14	14	14	14	13	13	14.7	99.0	4.1
	Mar	17	19	20	19	19	19	21	23	23	22	21	21	20	20	19	19	18	18	16	16	19.6	145.5	6.1
	April	21	22	22	22	22	21	22	23	23	22	22	21	21	20	20	19	19	18	18	16	20.7	149.2	6.2
	May	26	27	28	27	26	27	29	32	31	30	30	29	26	23	22	21	21	21	19	18	25.7	190.9	8.0
	June	23	25	27	27	28	28	30	32	33	33	32	31	30	27	26	25	24	23	23	22	27.5	198.2	8.3
	Jul	26	28	29	27	25	26	29	31	31	29	28	27	26	23	19	18	18	15	15	13	24.1	179.5	7.5
	Aug	33	36	39	38	37	37	39	42	40	39	36	33	31	30	28	27	24	23	22	20	32.6	242.8	10.1
	Sept	19	21	21	21	19	19	23	25	27	25	24	23	21	20	19	18	15	15	14	12	20.2	145.1	6.0
	Oct	21	22	23	23	22	22	25	28	28	28	27	25	25	23	19	18	17	16	15	15	22.0	163.9	6.8
	Nov	23	24	24	23	21	20	21	23	22	20	18	16	16	15	13	11	10	10	10	9	17.4	125.4	5.2
	Dec	20	22	24	25	24	24	27	29	28	28	27	26	24	23	21	20	19	17	16	15	22.9	170.6	7.1

79.8
21.9% Exceed
78.1% Meet

EPA
Moderate
Contract
CI 82%
Local Std Dev

E-coli - Percent of Time > 473 MPN/100ml

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
Avg	Jan	8	9	9	9	8	8	9	11	11	10	9	9	9	9	8	7	7	6	6	6	8.4	62.5	2.6
74-78	Feb	9	9	9	9	8	8	8	9	9	8	8	7	7	8	7	7	7	7	7	7	8.0	53.7	2.2
	Mar	12	13	13	13	13	13	15	16	16	14	14	13	12	12	11	11	11	11	10	10	12.7	94.4	3.9
	April	18	19	19	18	17	17	17	18	18	17	17	16	15	14	13	12	12	11	11	11	15.5	111.3	4.6
	May	18	19	19	19	17	17	17	20	20	19	18	16	15	14	14	13	13	12	12	12	16.2	120.4	5.0
	June	21	22	22	22	22	22	23	26	27	26	24	23	22	21	20	20	19	19	18	17	21.7	156.6	6.5
	Jul	20	21	21	19	19	17	19	22	22	20	19	16	13	12	12	11	10	9	8	8	15.9	118.6	4.9
	Aug	24	25	26	25	24	23	25	28	28	27	25	23	22	21	20	18	18	16	15	13	22.3	165.6	6.9
	Sept	13	14	15	15	14	14	18	21	21	18	16	14	13	12	11	10	10	9	8	7	13.6	98.0	4.1
	Oct	16	17	18	18	17	16	18	19	20	18	16	15	14	13	12	12	12	11	11	9	15.0	111.8	4.7
	Nov	15	15	14	13	13	12	12	14	14	13	12	11	9	8	7	7	6	6	6	6	10.7	77.0	3.2
	Dec	15	15	15	15	15	14	16	18	17	16	15	13	12	12	10	10	10	9	9	9	13.2	98.4	4.1

52.8
14.5% Exceed
85.5% Meet

E-Coli - Monthly Geometric Mean (#/100ml)

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Reach Average	Peak	
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
Avg	Jan	56	65	69	67	65	66	72	78	79	77	76	74	73	70	67	64	62	59	57	56	67.6	79.3	
74-78	Feb	54	58	60	60	58	59	62	66	66	64	63	62	61	59	57	56	54	52	50	49	58.4	65.7	
	Mar	56	63	67	66	64	66	74	80	82	80	78	77	76	74	72	70	68	65	64	62	70.1	81.7	
	April	86	91	93	91	89	89	93	97	97	95	93	92	91	88	86	84	82	80	79	77	88.7	97.3	
	May	125	138	146	146	143	144	156	167	168	163	156	149	142	134	125	118	110	104	99	95	136.4	168.5	
	June	115	124	131	131	127	128	138	148	149	144	138	131	126	120	113	107	101	96	91	88	122.3	148.9	
	Jul	113	126	131	127	119	120	132	143	142	133	123	114	107	98	89	81	74	69	65	62	108.3	142.9	
	Aug	180	205	217	212	200	197	210	221	218	204	188	174	162	150	137	125	115	108	102	97	171.1	221.3	
	Sept	73	82	86	83	79	81	92	101	102	96	90	84	81	75	70	64	60	57	55	54	78.2	101.6	
	Oct	78	87	90	87	81	79	86	92	90	85	79	74	70	65	59	54	50	47	45	44	72.2	91.9	45 days>126
	Nov	84	92	94	89	83	81	87	92	91	84	78	72	67	62	56	52	48	45	43	41	72.0	94.2	240 Total Days
	Dec	71	85	93	95	93	95	105	114	116	113	110	107	105	101	96	91	86	81	77	74	95.4	115.8	81.3% Compliance

Illness Rate per 1,000 Swimmers based on E-Coli - Monthly Geometric Mean

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Risk Assessment % of Swimmers Average	Peak
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8		
Avg	Jan	4.7	5.3	5.5	5.5	5.3	5.3	5.7	6.1	6.1	6.0	5.9	5.8	5.8	5.6	5.4	5.3	5.1	4.9	4.8	4.7	0.54%	0.61%
74-78	Feb	4.5	4.9	5.0	5.0	4.9	4.9	5.1	5.3	5.3	5.2	5.2	5.1	5.0	4.9	4.8	4.7	4.5	4.4	4.3	4.1	0.49%	0.53%
	Mar	4.7	5.2	5.4	5.4	5.2	5.4	5.8	6.2	6.2	6.1	6.1	6.0	5.9	5.9	5.7	5.6	5.5	5.3	5.2	5.1	0.56%	0.62%
	April	6.5	6.7	6.8	6.7	6.6	6.6	6.8	6.9	6.9	6.9	6.8	6.7	6.7	6.6	6.5	6.4	6.3	6.2	6.1	6.0	0.66%	0.69%
	May	8.0	8.4	8.6	8.6	8.5	8.6	8.9	9.2	9.2	9.0	8.9	8.7	8.5	8.3	8.0	7.7	7.5	7.2	7.0	6.8	0.83%	0.92%
	June	7.6	8.0	8.2	8.2	8.0	8.1	8.4	8.7	8.7	8.5	8.4	8.2	8.0	7.8	7.6	7.3	7.1	6.9	6.7	6.5	0.78%	0.87%
	Jul	7.6	8.0	8.2	8.0	7.8	7.8	8.2	8.5	8.5	8.2	7.9	7.6	7.3	7.0	6.6	6.2	5.8	5.5	5.3	5.1	0.73%	0.85%
	Aug	9.5	10.0	10.2	10.1	9.9	9.8	10.1	10.3	10.2	10.0	9.6	9.3	9.0	8.7	8.3	8.0	7.6	7.4	7.1	6.9	0.91%	1.03%
	Sept	5.8	6.2	6.4	6.3	6.1	6.2	6.7	7.1	7.1	6.9	6.6	6.4	6.2	5.9	5.6	5.3	5.0	4.8	4.7	4.5	0.60%	0.71%
	Oct	6.1	6.5	6.6	6.5	6.2	6.1	6.4	6.7	6.6	6.4	6.1	5.8	5.6	5.3	4.9	4.6	4.2	4.0	3.8	3.8	0.56%	0.67%
	Nov	6.4	6.7	6.8	6.6	6.3	6.2	6.5	6.7	6.7	6.4	6.0	5.7	5.4	5.1	4.7	4.4	4.0	3.8	3.6	3.5	0.56%	0.68%
	Dec	5.7	6.4	6.8	6.8	6.8	6.8	7.2	7.6	7.7	7.6	7.5	7.3	7.3	7.1	6.9	6.7	6.4	6.2	6.0	5.8	0.68%	0.77%

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State WQS
CI 75%
State Std Dev

E-Coli - Percent of Time > 235 MPN/100ml

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Reach		
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8	Average	Hrs/mo	days/yr
Avg	Jan	15	17	19	18	17	17	19	21	22	22	22	20	19	18	18	18	17	17	16	16	18.4	136.6	5.7
74-78	Feb	17	19	19	18	17	17	19	21	21	19	19	19	18	18	17	16	16	16	15	15	17.7	119.2	5.0
	Mar	18	21	22	22	22	21	24	27	28	27	26	25	25	24	23	22	21	20	19	19	22.8	169.3	7.1
	April	27	28	29	27	26	26	26	28	28	26	26	24	23	23	22	22	21	20	20	19	24.7	177.6	7.4
	May	31	31	33	33	33	33	35	38	38	36	35	34	33	32	29	27	26	25	25	25	31.7	235.6	9.8
	June	28	30	31	31	32	31	33	35	36	35	35	35	34	33	31	30	29	27	26	25	31.3	225.5	9.4
	Jul	28	30	32	32	30	30	33	37	35	34	32	30	29	27	26	23	21	20	19	18	28.5	211.7	8.8
	Aug	38	41	44	43	41	41	44	46	46	45	42	39	37	35	33	31	30	28	25	22	37.5	279.0	11.6
	Sept	22	25	26	26	24	24	26	28	29	28	26	25	25	22	21	20	19	18	18	16	23.5	168.9	7.0
	Oct	25	26	27	28	26	27	29	32	31	30	29	27	26	25	24	23	20	19	18	17	25.5	189.7	7.9
	Nov	26	26	27	26	25	24	25	28	27	25	23	22	21	19	18	17	16	14	12	12	21.7	156.1	6.5
	Dec	23	26	28	29	28	28	30	33	32	32	31	30	30	29	27	25	24	23	22	22	27.6	205.5	8.6

94.8
26.0% Exceed
74.0% Meet

State WQS
CI 75%
Local Std Dev

E-Coli - Percent of Time >334 MPN/100ml

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
Avg	Jan	11	12	13	12	12	11	13	16	16	15	15	14	13	13	12	11	11	11	11	10	12.6	93.6	3.9
74-78	Feb	14	14	14	14	14	13	14	15	15	15	15	14	14	14	13	13	13	12	11	10	13.6	91.3	3.8
	Mar	17	18	18	18	18	17	18	21	21	20	19	19	18	17	17	17	15	14	13	13	17.4	129.6	5.4
	April	20	21	22	21	21	21	21	22	22	21	20	20	20	19	18	17	17	15	15	15	19.4	139.6	5.8
	May	23	24	24	24	24	24	26	29	28	28	27	25	23	21	20	18	18	17	17	16	22.7	169.0	7.0
	June	22	24	25	26	26	26	29	31	32	30	30	29	28	26	25	24	22	21	21	20	25.8	185.6	7.7
	Jul	24	25	26	25	24	24	26	28	28	27	26	24	22	19	16	15	14	12	12	12	21.4	159.5	6.6
	Aug	30	33	35	34	32	32	34	37	37	34	31	29	27	25	24	22	21	19	18	16	28.6	212.5	8.9
	Sept	17	17	19	19	18	18	22	24	25	24	23	22	20	19	16	15	14	13	11	11	18.3	131.9	5.5
	Oct	19	20	21	21	21	21	24	26	26	26	25	23	21	18	18	17	15	15	14	13	20.2	150.0	6.3
	Nov	22	22	22	20	18	17	19	21	19	18	15	14	13	13	10	10	9	9	9	8	15.4	111.1	4.6
	Dec	19	21	22	22	21	21	24	26	27	26	24	23	21	19	18	17	16	14	13	12	20.3	150.8	6.3

71.9
19.7% Exceed
80.3% Meet

EPA
Moderate
Contract
CI 82%
State Std Dev

E-coli - Percent of Time > 298 MPN/100ml

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
Avg	Jan	11	14	14	13	13	13	15	18	18	17	16	16	15	15	15	14	12	12	12	11	14.2	105.4	4.4
74-78	Feb	14	15	15	15	14	14	15	17	17	16	16	15	15	15	14	14	14	14	13	13	14.7	99.0	4.1
	Mar	17	19	20	19	19	19	21	23	23	22	21	21	20	20	19	19	18	18	16	16	19.5	145.4	6.1
	April	21	22	22	22	22	21	22	23	23	22	22	21	21	20	20	19	19	18	18	16	20.7	149.2	6.2
	May	26	27	28	27	26	27	29	32	31	30	30	29	26	23	22	21	21	20	19	18	25.6	190.7	7.9
	June	23	25	27	27	28	28	30	32	33	33	32	31	30	27	26	25	24	23	23	22	27.5	197.8	8.2
	Jul	26	28	29	27	25	26	29	31	30	28	27	27	25	23	19	18	17	15	14	13	23.8	177.4	7.4
	Aug	32	35	38	38	37	36	39	41	39	38	35	32	30	28	27	25	23	21	20	18	31.5	234.4	9.8
	Sept	19	21	21	21	19	19	23	25	27	25	24	23	21	20	19	17	15	15	14	12	20.1	144.6	6.0
	Oct	21	22	23	23	22	22	24	28	28	28	26	25	24	23	19	18	17	16	15	15	21.9	163.2	6.8
	Nov	23	24	24	23	21	20	21	23	22	20	18	16	16	15	13	11	10	10	10	9	17.4	125.2	5.2
	Dec	20	22	24	25	24	24	27	29	28	28	27	26	24	23	21	20	19	17	16	15	22.9	170.6	7.1

79.3
21.7% Exceed
78.3% Meet

EPA
Moderate
Contract
CI 82%
Local Std Dev

E-coli - Percent of Time > 473 MPN/100ml

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1			
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8			
Avg	Jan	8	9	9	9	8	8	9	11	11	10	9	9	9	9	8	7	7	6	6	6	8.4	62.5	2.6
74-78	Feb	9	9	9	9	8	8	8	9	9	8	8	7	7	8	7	7	7	7	7	7	8.0	53.7	2.2
	Mar	12	13	13	13	13	13	15	16	16	14	14	13	12	12	11	11	11	11	10	10	12.7	94.4	3.9
	April	18	19	19	18	17	17	17	18	18	17	17	16	15	14	13	12	12	11	11	11	15.4	111.2	4.6
	May	18	19	19	19	17	17	17	20	20	19	18	16	15	14	14	13	13	12	12	12	16.1	120.1	5.0
	June	21	22	22	22	22	22	23	26	27	26	24	23	21	21	20	19	19	18	18	17	21.7	156.0	6.5
	Jul	19	21	21	19	18	17	19	21	22	20	19	15	13	12	12	11	10	9	8	7	15.7	116.6	4.9
	Aug	23	24	24	24	23	22	24	28	28	26	25	23	22	20	18	17	16	13	12	11	21.1	156.9	6.5
	Sept	13	14	15	15	14	14	18	21	21	18	16	14	13	12	11	10	10	9	8	7	13.5	97.5	4.1
	Oct	16	17	18	18	17	16	18	19	20	18	16	15	14	13	12	12	12	11	10	9	15.0	111.3	4.6
	Nov	15	15	14	13	13	12	12	14	14	13	12	11	9	8	7	7	6	6	6	6	10.7	77.0	3.2
	Dec	15	15	15	15	15	14	16	18	17	16	15	13	12	12	10	10	10	9	9	9	13.2	98.4	4.1

52.3
14.3% Exceed
85.7% Meet

E-Coli - Monthly Geometric Mean (#/100ml)

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Reach		
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8	Average	Peak	
Avg	Jan	56	65	69	67	65	66	72	78	79	77	76	74	73	70	67	64	62	59	57	56	67.6	79.3	
74-78	Feb	54	58	60	60	58	59	62	66	66	64	63	62	61	59	57	56	54	52	50	49	58.4	65.7	
	Mar	56	63	67	66	64	66	74	80	82	80	78	77	76	74	72	70	68	65	64	62	70.1	81.7	
	April	86	91	93	91	89	89	93	97	97	95	93	92	91	88	86	84	82	80	79	77	88.7	97.2	
	May	125	138	146	146	142	144	156	167	168	163	156	149	142	134	125	117	110	104	99	95	136.3	168.4	
	June	114	124	131	130	127	128	138	148	149	144	137	131	126	120	113	107	101	95	91	87	122.1	148.8	
	Jul	111	123	128	124	116	117	129	140	139	130	120	111	104	95	86	78	71	66	63	59	105.6	139.7	
	Aug	164	187	197	192	181	179	190	202	199	187	173	160	150	138	127	116	107	100	95	90	156.7	201.6	
	Sept	73	81	85	82	78	81	92	101	101	95	89	83	80	74	68	63	58	56	54	53	77.4	100.9	
	Oct	78	86	90	86	80	79	85	91	90	85	79	74	70	65	59	54	50	47	45	44	71.8	91.4	44 days>126
	Nov	84	92	94	89	83	81	87	92	91	84	78	72	67	62	56	52	47	44	43	41	71.9	94.2	240 Total Days
	Dec	71	85	93	95	93	95	105	114	116	113	110	107	105	101	96	91	86	81	77	74	95.4	115.8	81.7% Compliance

Illness Rate per 1,000 Swimmers based on E-Coli - Monthly Geometric Mean

Year	Month	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Risk Assessment % of Swimmers	
		98.9	97.8	96.8	95.8	94.8	93.8	92.8	91.8	90.8	89.8	88.8	87.8	86.8	85.8	84.8	83.8	82.8	81.8	80.8	79.8	Average	Peak
Avg	Jan	4.7	5.3	5.5	5.5	5.3	5.3	5.7	6.1	6.1	6.0	5.9	5.8	5.8	5.6	5.4	5.3	5.1	4.9	4.8	4.7	0.54%	0.61%
74-78	Feb	4.5	4.9	5.0	5.0	4.9	4.9	5.1	5.3	5.3	5.2	5.2	5.1	5.0	4.9	4.8	4.7	4.5	4.4	4.3	4.1	0.49%	0.53%
	Mar	4.7	5.2	5.4	5.4	5.2	5.4	5.8	6.2	6.2	6.1	6.1	6.0	5.9	5.9	5.7	5.6	5.5	5.3	5.2	5.1	0.56%	0.62%
	April	6.4	6.7	6.8	6.7	6.6	6.6	6.8	6.9	6.9	6.9	6.8	6.7	6.7	6.6	6.5	6.4	6.3	6.2	6.1	6.0	0.66%	0.69%
	May	8.0	8.4	8.6	8.6	8.5	8.6	8.9	9.2	9.2	9.0	8.9	8.7	8.5	8.3	8.0	7.7	7.5	7.2	7.0	6.8	0.83%	0.92%
	June	7.6	7.9	8.2	8.1	8.0	8.1	8.4	8.7	8.7	8.5	8.4	8.2	8.0	7.8	7.6	7.3	7.1	6.9	6.7	6.5	0.78%	0.87%
	Jul	7.5	7.9	8.1	7.9	7.7	7.7	8.1	8.4	8.4	8.1	7.8	7.5	7.2	6.9	6.5	6.1	5.7	5.4	5.2	4.9	0.71%	0.84%
	Aug	9.1	9.6	9.8	9.7	9.5	9.4	9.7	9.9	9.9	9.6	9.3	9.0	8.7	8.4	8.0	7.7	7.3	7.1	6.9	6.6	0.88%	0.99%
	Sept	5.8	6.2	6.4	6.3	6.1	6.2	6.7	7.1	7.1	6.8	6.6	6.3	6.1	5.9	5.5	5.2	4.9	4.7	4.6	4.4	0.59%	0.71%
	Oct	6.0	6.5	6.6	6.4	6.2	6.1	6.4	6.7	6.6	6.4	6.1	5.8	5.6	5.3	4.9	4.5	4.2	4.0	3.8	3.7	0.56%	0.67%
	Nov	6.4	6.7	6.8	6.6	6.3	6.2	6.5	6.7	6.7	6.4	6.0	5.7	5.4	5.1	4.7	4.4	4.0	3.7	3.6	3.4	0.56%	0.68%
	Dec	5.7	6.4	6.8	6.8	6.8	6.8	7.2	7.6	7.7	7.6	7.4	7.3	7.3	7.1	6.9	6.7	6.4	6.2	6.0	5.8	0.68%	0.77%

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